NBS TECHNICAL NOTE 888

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Nuclear Science Education Day

NATIONAL BUREAU OF STANDARDS

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Office of Standard Reference Data — Office of Information Activities — Office of Technical Publications — Library — Office of International Relations — Office of International Standards.

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.

[2] Located at Boulder, Colorado 80302.

Nuclear Science Education Day

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Edited by

F. J. Shorten

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"Apart from the Welcoming Address by Dr. Ambler, the comments expressed in the various invited papers represent the views of the authors of the papers or their organizations, and do not necessarily represent the views of the National Bureau of Standards."

PREFACE

A Nuclear Science Education Day was presented at the National Bureau of Standards on November 29, 1973. The purpose of the meeting was to provide information to high school science teachers and outstanding students on:

1. The various research and development aspects of the application of nuclear energy,

2. The interrelations between man, the environment and nuclear energy,

3. Present research frontiers in the use of nuclear techniques and nuclear energy,

4. Career and educational opportunities in nuclear science.

Attendees were teachers, students and special guests from Northern Virginia, the District of Columbia and Maryland. The affair was co-sponsored by tne National Bureau of Standards and the Washington Section of the American Nuclear Society. The Program Committee consisted of the following:

Dr. Robert Carter, NBS Liaison, National Bureau of Standards.

Dr. Dick Duffy, ANS Liaison, University of Maryland.

Dr. George Ferguson, Master of Ceremonies, Howard University.

Dr. Bobby Leonard, Program Coordinator, Catholic University and Institute for Resource Management, Inc.

Dr. Arthur Randol III, Finance Coordinator, Potomac Electric Power Company.

Mr. Fred Shorten, Arrangements Coordinator, National Bureau of Standards.

Financial support for the meeting was provided by:

Babcock and Wilcox Company

Baltimore Gas and Electric Company

Bechtel Corporation

Combustion Engineering Company

General Electric Company

Nuclear Associates International

NUS Corporation

Pickard, Lowe, and Associates

Potomac Electric Power Company

Westinghouse Electric Corporation

After the program sessions were completed, a tour of the National Bureau of Standards Research Nuclear Reactor and associated laboratories was conducted by the reactor staff.

ABSTRACT

These proceedings are a collection of invited papers given at the Nuclear Science Education Day Conference held on November 29, 1973 at the National Bureau of Standards, Gaithersburg, MD. The program was sponsored jointly by the ANS (Washington Chapter) and the NBS for secondary school science teachers and outstanding science students in the Washington area. Four main topics are covered: research and development in nuclear energy applications; man, environment and nuclear energy; nuclear science frontiers; and career opportunities in nuclear science.

Key words: Biology; career; ecological; electricity; energy; environment; fusion; medicine; nuclear; power; radiation; reactor; research; utilities.

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WELCOMING ADDRESS

Dr. E. Ambler
(Deputy Director, Bureau of Standards, Washington, D.C.)

I'm happy to welcome you as teachers and students to the National Bureau of Standards for two reasons. First, let me mention a personal point of view. I have two boys, one 13 years old in Pyle Junior High School and one 15 in Walt Whitman High School. The fine teaching they are getting in science and other subjects has done a lot for them. So, in return, I'm glad to do anything I can to make your stay pleasant and profitable.

Then, secondly, as deputy director of a scientific institution, I can say that we at NBS are happy you've come. The connections between the educational community and the Bureau are very close -- they've always been close. Many of our staff are sent back to universities for courses and training of various types, many of our staff teach at local universities, and we have strong interactions with school programs. For example, our summer program is very strongly related to high school students. We help in such activities as the Westinghouse Science Talent Search, the U.S. Mathematical Olympiad, and we try to establish contacts with you to exchange ideas about education and about science in general.

Your meeting here today is particularly timely, I think. Nuclear technology is something everyone is concerned with these days because of the energy crisis. And while it is true that nuclear power will not help us a great deal this winter, nevertheless, in the long term, we can see that nuclear technology and coal technology are going to be exploited in order to insure that this country is going to be independent as far as energy sources are concerned.

The Bureau of Standards is deeply involved in nuclear technology and has been ever since nuclear science was discovered back in 1931. The Bureau was involved in an interesting way through its cryogenics program, which provides an example of how science is really one subject, and one area of speciality tends to relate to another in unexpected ways. It was NBS cryogenics scientists who succeeded in distilling liquid hydrogen and producing a sufficient concentration of heavy hydrogen to enable Harold Urey at Columbia University to make a positive identification, spectroscopically, of deuterium. Of course, you know that deuterium in its chemical compound, heavy water, now plays an important role in many reactors.

Many of you have read that when the nuclear energy age dawned, Albert Einstein wrote to the President suggesting that an atomic bomb should be built. Well, probably what isn't so well known is that the first man that President Roosevelt turned to was the Bureau Director, at that time Lyman Briggs, and the Bureau was involved in the planning of the Manhattan Project. Enough of the historical involvement, although I think it is important to consider these aspects because science is an evolving subject and it is good to know where our roots are planted.

The most fully developed alternative to fossil fuel as an energy source is nuclear energy, but even the supply of nuclear fuel used in the present power reactors is limited. A new class of reactors called breeder reactors is being developed. As you know, breeder reactors will produce more fissionable material than they use, thus greatly increasing our fuel resources. Here again the Bureau is helping to develop this new class of reactor by providing data and standards of radiation fields that will enable these reactors to be better designed and more efficient. You will probably see some of this work on a tour this afternoon at the research reactor, where a good deal is being done.

We have extensive programs in radioactivity, like the work we do to develop standard reference materials. The range of SRM applications is broad. For instance, they are used to aid the monitoring of the environment with respect to nuclear reactors. This helps with water pollution control. But other radioactivity SRM's are used in the medical field for radio pharmaceutical standards and for X-ray and other exposure standards essential to diagnosis and treatment.

You will learn much more about the nuclear field from the conference today. You will explore in depth both the benefits and the problems associated with nuclear technology. Because of the impact that nuclear technology may have on our lives, it is important that the consequences be communicated to the general public and widely understood so that people can evaluate the risks and benefits and make the trade-offs that are going to be necessary in the future. I think you as science teachers and students have a very important function to perform. I think that the future voting public are going to have to be called upon to make decisions about how much nuclear power will be developed, where it will be located, and what the effect on the environment will be. We cannot make these decisions unless we are informed. So I think this seminar is particularly important and particularly timely, and we at the Bureau of Standards are very pleased that you have come here to join in this activity. I hope you enjoy it, I hope you benefit from it, and I hope you have a successful day. Thank you very much.

NUCLEAR SCIENCE DAY - WELCOME

D. Duffy
(University of Maryland, College Park, Md.)

The aim of the American Nuclear Society is to provide the advancement of science and engineering relating to the atomic nucleus. We are well aware of the controversy over the applications of nuclear reactions, particularly nuclear power plants; there is similar concern over chemical power units, such as automobiles and fossil fuel utility operations. Nevertheless, financial commitments have been made, and the nuclear efforts of the U.S. will be a major influence in the country's energy program and in related scientific and industrial endeavors.

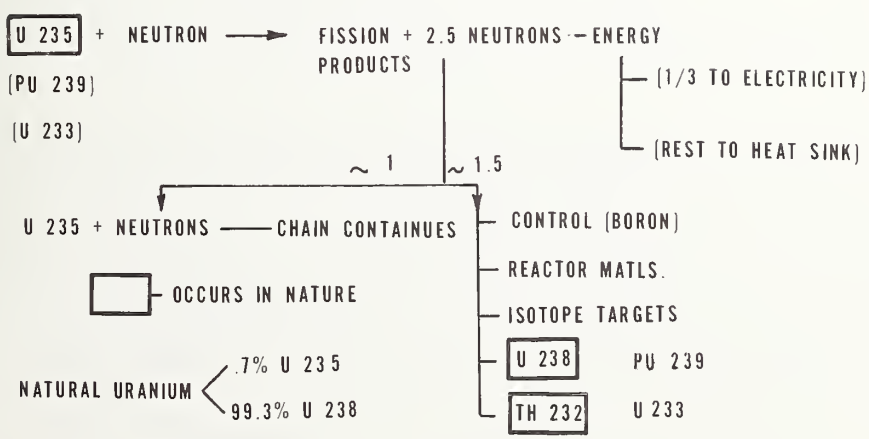
In view of this, the American Nuclear Society has sponsored many meetings to help acquaint teachers and students with both the scientific basis of the nuclear field and with the applied activities. Consequently, the Washington Section of the American Nuclear Society and our host, the National Bureau of Standards, with the financial help of local industrial groups, have arranged a Nuclear Science Day.

The following comments relating to electrical power stations will lay some basis for the presentations to follow and will indicate the large scale effort and hence sizeable financial investments involved in nuclear work.

Now fossil fuels are supplying most of the electrical power of the United States. For example, a large coal fired plant near Shiprock, New Mexico on the Navajo Indian Reservation produces about the same amount of power as one of the reactors at the Calvert Cliff station or the planned Douglas Point facility. Such coal plants have provided much of our central station power for years, and hence, have general public acceptance. Nevertheless, these fossil fuel operations are now becoming a part of the environmental discussion, and this plant, even though in a very remote area, is the subject of criticism because of its local strip mine and the fumes from the stacks. The cooling pond limits thermal pollution to the property, but, of course, precious water is consumed in evaporation. It should be noted that a coal plant releases some radioactive materials because of the uranium, thorium, and potassium in rocks, and hence coal, and the environmental analyses for a coal plant must consider these nuclear problems.

Most of the nuclear efforts of the U.S. relate directly or indirectly to the fission reaction.

NUCLEAR FISSION REACTION



This nuclear fission reaction depends on the three long lived nuclides in nature, namely, U 235 (which fissions) and U 238 and Th 232 that can be converted in a reactor to fissionable nuclides, Pu 239 and U 233. Many industrial and medical applications of radioactive materials, e.g., Co 60 for radiation therapy and Tc 99m for diagnostic procedures, are based on neutrons from this reaction. The engineering problems are the well known ones of the radioactive fission products, that must be confined, and the heat rejection, as in conventional plants.

To apply this reaction, the uranium fuel must be assembled.

A fuel unit for a nuclear reactor contains about 150 tubes, about 1/2 inch in diameter and 15 ft. long filled with uranium oxide; about 200 such assemblies nested together in a pressure vessel constitutes the core of a reactor. Control is by boron containing assemblies, perhaps a 100, fitting into the fuel units. The pressure vessel maybe 40 ft. high and 15 ft. in diameter and weighing 500 tons contains the reacting mass and the water coolant and moderator.

Hot water from the pressure vessel may go to a steam generator about the same physical size as the pressure vessel. All this equipment which holds the fission products is further confined in a containment structure so as to prevent any releases of radioactive materials to the public. The turbine receives the steam and produces electricity with the reject heat to a sink, e.g., a cooling pond. In the U.S. something like 175 of these large reactors are now under construction or planned. In addition, much nuclear activity related to non-power, e.g., industrial and medical isotopes. All this effort must be supported by research and development in nuclear science and this talent must be a product of your educational efforts in science. It is hoped that this Science Day program will add to your lore of nuclear knowledge and benefit your educational activities.

NUCLEAR POWER: EVERYONE'S INVOLVED

J. L. Liverman
(U.S. Atomic Energy Commission, Washington, D.C.)

It is a personal pleasure for me to have this opportunity to participate in Nuclear Science Education Day, since I have spent nearly half of my life as a student and a teacher. I look forward to every opportunity to meet with students and especially with those who have a clearly demonstrated interest in science and who have become outstanding science students. Continue your accomplishments! Our country's future may well rest in your hands and sooner than you think. I will return to this point later.

The American Nuclear Society and those organizations that have shared in sponsoring this program also deserve a special word of praise for their efforts to promote an understanding of the energy problem generally, and more especially of nuclear energy. Educational experiences such as you are enjoying today are absolutely essential if you are to understand what nuclear energy is about and how it plus all other available energy sources must be used to supply our demands.

I understand that later today Dr. Victor Bond of Brookhaven National Laboratory is to discuss research in nuclear medicine and its use in the diagnosis and treatment of many human diseases. Nuclear energy also has been useful in tracing sources of environmental pollution, for providing electrical power for use in space, for stimulating gas production (by nuclear explosions), as a power source for heart pacemakers, and for other exciting applications. Later Dr. Glenn Graves, a scientist from the Los Alamos Scientific Laboratory, plans to discuss research in fusion which unlike fission will join atoms together rather than split them apart. Both processes yield energy, but we only know how to capture that from fission--in the fission reactor--a use of nuclear energy that almost everyone is talking about but which very few really know much about. It is in this area that I want to spend most of my time.

Before I discuss nuclear energy, however, it is important to put in perspective for you the whole energy problem as we are now facing it and to describe briefly the energy R&D planning exercise in which I have been involved for the past five months. Why do we have an energy problem? One of the reasons is that the U.S. with less than 6% of the world's population uses 35% of the energy consumed in the world. That sounds impressive, but when those figures are translated into real life uses, an energy shortage becomes quite personal. The billions of BTU's consumed in the U.S. in 1970, for example, supplied power and heat to some 60 million homes; powered 110 million vehicles; produced 1000 lbs. of steel, 2000 lbs. of food, and 60 lbs. of cloth for every man, woman and child in the country. In all, our energy use is equivalent to approximately 80 slaves per person. Of course, we can and we will find ways to cut back on energy consumption and plug up any waste. But that alone is not enough as you are certainly aware from the reduced speed limits just imposed and the still imminent gas and fuel shortage being projected. Our problem is basically a demand that exceeds supply. This is shown graphically in Figure 1 which is taken from a staff study for the Joint Committee on Atomic Energy of the U.S. Congress.

In view of the marked shortage on imports brought about by the Arab embargo we clearly must ask "what are our energy options--both supply and demand--at this time?" The issues will become clearer from a look at Figure 2 taken from the same JCAE report which shows the sources of our energy and their end use patterns in 1970. A major portion of our oil goes into transportation, but important amounts also move into industrial and commercial use with somewhat less being used for home heating, and central station power generation. Natural gas moves in a major way into industrial and commercial channels and home heating with somewhat less going to generate central station power. An important point here is that there have been large recent shifts toward use of these two now "in-short-supply" resources in central station power generation because of their cleanliness as compared to coal.

Perhaps against this backdrop the recent Presidential announcements concerning shift-

ing from gas and oil to coal for the central station power use and for industrial and commercial use where possible makes more sense. Also the reason for slower speeds on the highway and more car pooling then begins to make more sense as a quick response, short term measure.

Clearly we must assess the state of our own natural resources. Coal is abundant but it is dirty and creates problems when mined and transported and burned. Domestic oil and gas that can be obtained just by drilling is very limited even though relatively large quantities exist in shale and off-shore areas but the methods for obtaining it are either not well developed or legal issues constrain the use of these sources. Hydroelectric sources are already contributing near their maximum and, while this source is important in some local regions, its input to the total energy requirement of the nation is sorely limited. We find the contribution from nuclear stations at this point minimal although the promise for much larger contributions during the next five years is very good. Nuclear will contribute a much larger percentage by 1990. Power from fusion, geothermal, solar, wind, bioconversion, ocean gradients and other specialized sources are not yet adequately developed and cannot contribute very much in the short term.

We have looked at our energy demands, at our current use patterns and at our resources for solving our own problems so let us return once again to the question "What are our options, and what do we do at this time? Clearly we must reach a stage of self sufficiency such that a threat of reduction of our imports cannot be used as an instrument of blackmail to cause us as a nation to do things we would not condone at other times. Operating within that constraint we must determine how best to use the resources we have. We must explore at least the following options and, if they are not fully available, to take the steps necessary to make them available:

1. Continue to import from dependable sources.
2. Reduce our needs and conserve our resources;
3. Increase the production of oil and gas;
4. Substitute coal for oil and gas where possible;
5. Guarantee the nuclear option; and
6. Exploit other potential energy sources.

But earlier I have mentioned that many of these options are not immediately available to us. You as students who have excelled in science know that one of the best insurance policies for keeping old options open and for creating new options is research and development. It is on that basis then I believe that the President on June 29 directed the Chairman of the AEC to do three things:

1. To prepare by September 1, 1973, recommendations for a $100 million increased spending on Energy R&D for FY 1974.

2. To prepare by December 1, 1973, a 5-year $10 billion R&D program on energy.

3. As part of the $10 billion program, to recommend specific funding for FY 1975.

Many hundreds of people have been involved in this exercise and I am most thankful that December 1 is right around the corner.

The first exercise for FY 1974 finally turned out to be a $115 million program with emphasis as shown in Figure 3.

In the $10 billion program about $3.7 billion will go for coal, oil and gas research; $5.9 billion for nuclear research, and an additional $400 million for solar, geothermal and miscellaneous areas such as conservation. The R&D programs are aimed directly at making available the large coal supplies, the yet untapped gas and oil reserves, and the full, rapid development of nuclear energy, as well as to explore solar and geothermal energy and to insure all possible conservation measures. In the short term, the R&D aims at making it possible to shift the use pattern from oil to coal as rapidly as possible, particularly

from oil and gas to coal for generating electricity.

An area of R&D which I have not mentioned before because it falls outside the $10 billion exercise but which is terribly important, is the environment--both ecological and health aspects. It is in fact the health effects and environmental impacts that cause the greatest concerns of the public for all energy forms, particularly nuclear. With fossil fuels the concerns are with SO_2, NO_x, CO, hydrocarbons, trace metals, particulates and waste heat. With nuclear power the public is concerned about the release and disposal of radioactive materials and with waste heat. All are important, but nuclear seems of greater public concern, perhaps for historical reasons related to its introduction into society as a secret weapon used for destructive purposes. It is difficult to reorient thinking towards its peaceful and beneficial uses.

Some people still believe that the internals of reactors are kept secret for security reasons, while in fact, reactor technology is open and available to the public. However, the technical aspects of nuclear technology are complex, and thus many non-scientific people are prone to avoid the subject. That is why it is important for you, your teachers, and others to find ways of explaining nuclear technology in understandable terms and to move from the emotional into a reasoned sphere.

Lately, nuclear power has been in the news locally. Baltimore Gas & Electric has built a plant at Calvert Cliffs, VEPCO has several nuclear plants, and PEPCO plans to build one nearby. The President has asked for speedier development of nuclear power in the face of energy shortages, while others have asked for a moratorium on nuclear power.

Nuclear power is not a novelty; in 1951 a few light bulbs were illuminated by power from an experimental reactor in Idaho. In 1957, the Shippingport Atomic Power Station in Pennsylvania began producing electricity for consumers. Today, (Figure 4) there are 37 nuclear plants which can provide the electricity needs of nearly 10 million people. There are another 57 reactors under construction and 89 planned. Nuclear power now supplies 5% of the Nation's electricity, but according to estimates, it is expected to supply 20% by 1980, and about 50% by 1990.

I don't want to give a crash course in reactor technology, but perhaps the visualization offered by Figure 5 would help. (Slide) A nuclear fission reactor is a type of furnace that uses uranium fuel instead of coal, oil or gas. Uranium-235 atoms are split (or fissioned), releasing heat energy and subatomic particles called neutrons which strike and fission yet other U-235 atoms, creating a chain reaction. The heat from this reaction turns water into steam, which is used to drive a turbine to make electricity. Incidentally, <u>it would take 3 million pounds of coal to equal the energy locked inside just one pound of uranium fuel</u>. The amount of heat created in the reactor core is regulated by control rods which can be moved up or down between the fuel rods. These rods contain material that act as a brake on the chain reaction; that is, when a rod is in the core it absorbs neutrons and prevents them from causing fissions and turns off the reactor.

As I mentioned earlier, present-day reactors rely on the fissionable Uranium-235 isotope for fuel, but this isotope represents less than 1% of the total energy available in uranium. That is why the AEC is working on a breeder reactor which can turn abundant (but non-fissionable) U-238 into a useful fuel, thus unlocking about 70% of the energy available in uranium and extending useable uranium fuels for centuries. The AEC, TVA, and Commonwealth Edison are cooperating in a top-priority program to build the first Liquid Metal Fast Breeder Reactor (LMFBR) demonstration project at Oak Ridge, Tennessee. I hope that each of you has an opportunity to visit the Breeder Exhibit that is on display in the lobby.

Briefly, the LMFBR would work this way: All of the neutrons released in a chain reaction do not strike U-235 atoms, so, by carefully arranging fissionable U-235 and surrounding it with a blanket of nonfissionable uranium (U-238) in a reactor, engineers can direct the unused neutrons at the U-238 atoms. When a neutron enters the nucleus of a U-238 atom it transforms it into U-239 which eventually decays to become Plutonium-239--

a fissionable material that can be used to fuel other reactors. Once this is achieved to the degree that more fuel is produced than consumed, it is said that the reactor is "breeding."

It is also imperative that we realize that R&D of any kind cannot go forward in isolation. Too often in the past R&D has become the victim of tunnel vision, of 'single-purposedness,' or parochial interest. Technologies were developed and research went forward without regard for an amalgam of social need, priority, interdisciplinary overlap, or environmental impact. But, with the environmental awakening of the late sixties, the inter-related and inter-dependent nature of the various segments of the scientific community came into focus. We can now see that scientists or engineers cannot perform effectively if isolated from related disciplines or from the public community; their work may not be directed to society's needs, their knowledge may be incomplete and their potential contributions may be ignored if not understood and accepted by people. My title as it appears on the program-Assistant General Manager for Biomedical and Environmental Research and Safety Programs--is a mouthful (even the abbreviation is unpronounceable: AGMBERSP), but it does show the reality of this inter-relationship.

The AEC spends nearly $1.5 billion a year conducting R&D. In some 30 laboratory facilities across the Nation, 25,000 scientists and engineers, including chemists, physicists, mathematicians, biomedical and environmental specialist, and engineers from many fields, work on nuclear R&D. Their efforts do not go on in isolation or in a haphazard fashion--there are focal points toward which lines of investigations are directed and for which bits and pieces of information from many projects help provide answers. One of these is the question--is nuclear energy a safe, economical, environmentally-acceptable way to generate electricity? The answer to that question cannot come from a closed-end process. It is an open-ended, on-going question which must, as Figure 6 shows, look in many diverse directions for answers.

What I want to emphasize this afternoon is that there are no easy or simple solutions to the energy dilemma we face. The problem cannot be solved by the wave of a one-answer-wand. Nuclear power isn't the complete answer. It is clear that we as a nation must attempt to balance our energy equation by using all possible sources of energy in as meaningful a strategy as we can devise. This view in fact is what is behind the President's proposal to convert the AEC into an Energy Research and Development Administration and make it responsible for the development of an adequate, safe, clean energy whatever its source. With that concept I fully agree. But let me return to nuclear energy.

If the breeder reactor is developed and researchers find a practical route to fusion, the spectre of a future energy shortage will pass, but when we think carefully about energy problems, we can see that they are very complex. Let's just take one example--the facet of timing. There are very short-term problems of what to do today and tomorrow; mid-range problems running well into the next century. Just sorting out all of these different parts of the problem is no easy task; the solutions of the problems will require all of the ingenuity of all of us for a long time.

All too often when something goes wrong, as it has in the energy field, the scene that follows is a frenzy of finger-pointing and name-calling. For some strange reason we demand a scapegoat, but this seldom serves a constructive purpose. Today we have so many scapegoats among us, it seems that there are more blamees than blamers. We blame the government, we blame business, we even blame entire segments of society. Unfortunately, we frequently overlook the fact that these groups reflect us as individuals and are no wiser or more ignorant than we are. As once said through the wisdom of "Pogo", "We have met the enemy and they are <u>us</u>."

The energy and environmental circumstances that we face today demand that each and everyone of us becomes aware of what the facts are, of what action is needed, and how each of us can help. There is no time for irresponsible behavior or scapegoating.

As I mentioned earlier, nuclear power is no secret. At the AEC we are determined to

make widespread unbiased information about nuclear energy available in many forms--films, speakers, booklets, workshops. Incidentally, I understand that many of the teachers in this audience took part in a workshop on energy and the environment that we co-sponsored recently with the University of Maryland. I hope you continue to make use of such information resources, because, while experts can formulate energy policies and engineers can find the needed technologies, unless people comprehend, acceptance won't come easy.

I firmly believe that achieving public understanding of nuclear energy is a number one priority--the importance of nuclear power in our Nation's energy game plan over the next few decades means we cannot afford the luxury of tolerating the nonsense and misconceptions about nuclear power that are being fed to the public from some sources. For example, if someone unfamiliar with nuclear power hears only from critics who paint horror stories of the hazards of radiation from nuclear plants, there's no wonder that that person might become hesitant about nuclear power. This nonsense must be put in perspective.

The public must know that radiation is a part of the natural environment; that, for example, anyone who takes a jet flight from New York to San Francisco receives ten times the radiation exposure that he would have received from nuclear power plant operations in this country. Why? Simply because of the increase of cosmic radiation at higher altitudes. Figure 7 shows a few other comparisons of radiation exposures that aren't too often thought about. As you can see, nuclear power doesn't rank very high as a source of radiation.

As I am confident, that given an opportunity to learn the facts Americans can and will demonstrate common sense about nuclear power. That is why I so strongly support programs such as today's, where students and teachers have an opportunity to meet face to face with experts of varying views in some cases, but with a sense of responsibility as a common denominator.

There's an ancient Chinese curse that goes "may you live in interesting times." There's no doubt that we are living in an interesting time--a complex time--but an exciting time. Crises aren't really catching up with us; we are simply becoming more alert to the world around us. This awareness, coupled with a research and development capability never before equalled in history, gives us an opportunity to create the quality of life we all want. But before R&D can move forward, before the public can decide wisely, we need accurate maps--accurate information--realistic criteria, in short, we need the kind of awareness that comes only from education.

I believe that the challenge in teaching science today is <u>not</u> the making of scientists. It lies in making science intelligible, and credible, to the great majority of students who do not intend to become scientists. Science has modified and tempered and powered the modern world. It affects everything we do and use. It should be understood by all citizens. The story of science is the history of man, from his first attempt to make a fire to his first footstep on the moon. If teachers convey even a fraction of this meaning of science, I believe more young people will reject the emotional criticism of science that is so fashionable today.

Not every student will end up loving science--that is not necessary--but everyone should at least be encouraged to try to understand more of our complex world, to the end that we can better care for the earth and its resources.

You individually and collectively can make major contributions toward seeing that our nation survives the present crisis! How? By bringing reason and judgment to the way we face the crisis. We can have the energy we desire and the healthy human environment we must have if we but put our mind to the task! Please do just that for it's the only Earth we'll ever have.

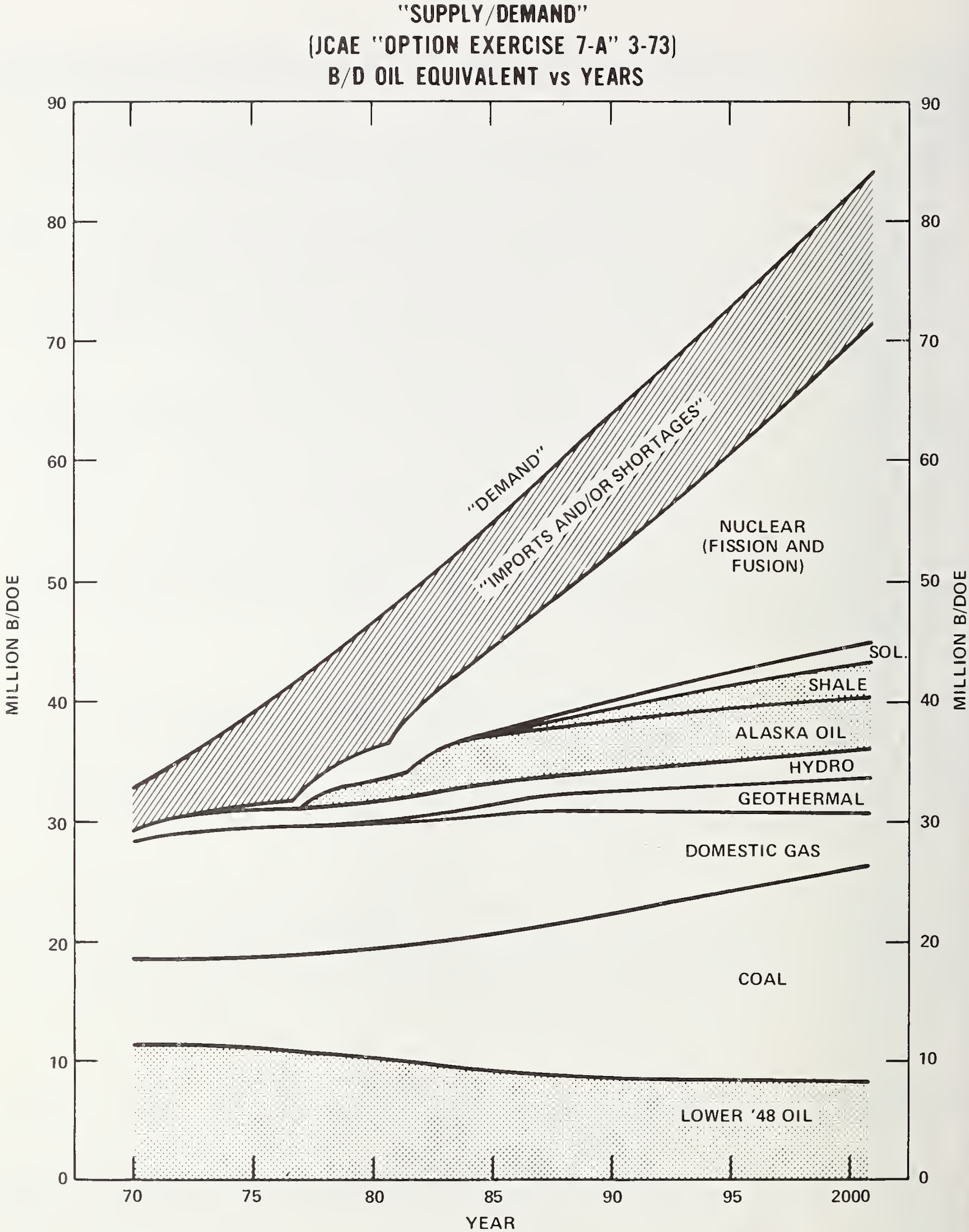

"SUPPLY/DEMAND"
(JCAE "OPTION EXERCISE 7-A" 3-73)
B/D OIL EQUIVALENT vs YEARS
MILLION B/DOE
"DEMAND"
"IMPORTS AND/OR SHORTAGES"
NUCLEAR (FISSION AND FUSION)
SOL.
SHALE
ALASKA OIL
HYDRO
GEOTHERMAL
DOMESTIC GAS
COAL
LOWER '48 OIL
YEAR
0
10
20
30
40
50
60
70
80
90
70
75
80
85
90
95
2000

Figure 1.

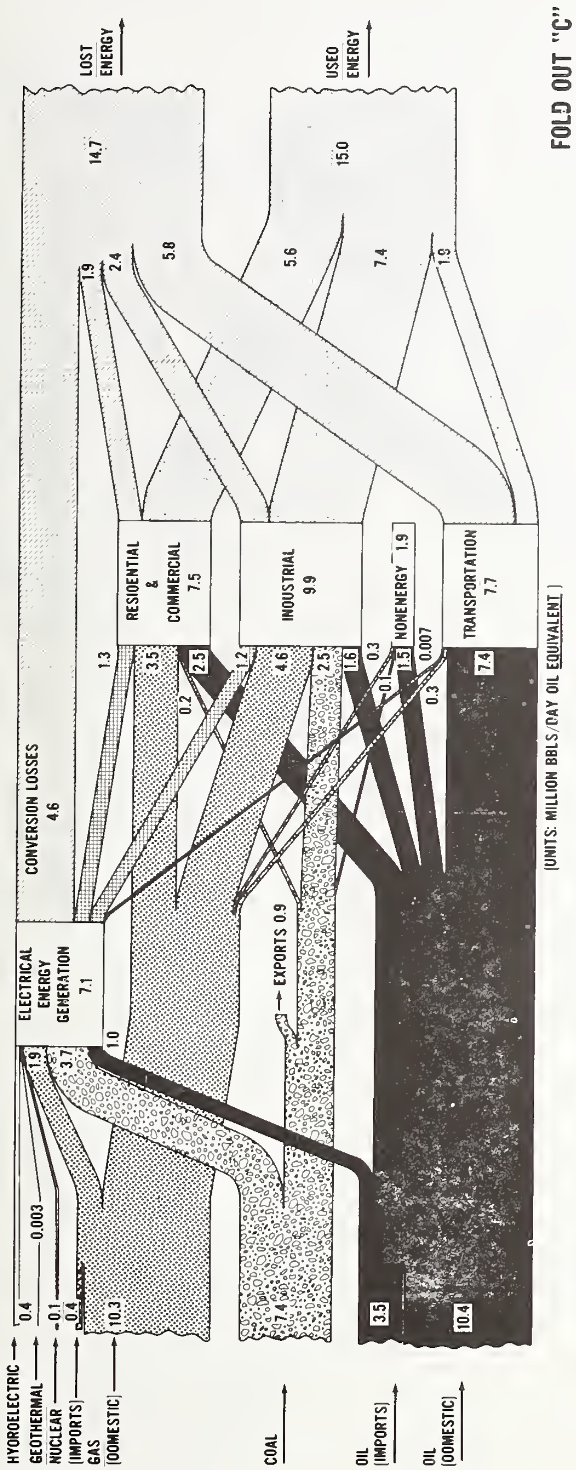

1970
HYDROELECTRIC
GEOTHERMAL
NUCLEAR (IMPORTS)
GAS (DOMESTIC)
COAL
OIL (IMPORTS)
OIL (DOMESTIC)
ELECTRICAL ENERGY GENERATION 7.1
CONVERSION LOSSES 4.6
RESIDENTIAL & COMMERCIAL 7.5
INDUSTRIAL 9.9
NONENERGY 1.9
TRANSPORTATION 7.7
EXPORTS 0.9
LOST ENERGY
14.7
USED ENERGY
15.0
(UNITS: MILLION BBLS/DAY OIL EQUIVALENT)
FOLD OUT "C"

Figure 2.

WHAT ARE OUR ENERGY OPTIONS NOW?

1. To reduce our needs and to conserve where possible;
2. To increase the production of oil and gas;
3. To substitute coal for oil and gas;
4. To guarantee the nuclear option; and
5. To exploit other potential energy sources.

PRESIDENTIAL DIRECTIVES

1. To prepare by September 1, 1973, recommendations for a $100 million increased spending on energy R & D for 1974.
2. To prepare by December 1, 1973, a 5 year $10 billion R & D program on energy.
3. As part of the $10 billion program to recommend specific funding for FY 1975.

ACCELERATED ENERGY PROGRAM

$100 Million "Add on" Exercise

Coal	$49.5
Petroleum and Natural gas	1.8
Geothermal	7.0
Solar	1.0
Nuclear	
Fission	7.0
Fusion	7.3
Conservation	6.4
Environmental	
Control Technology	11.7
Effects	5.7
Other	
	$115.0

Figure 3

NUCLEAR POWER REACTORS IN THE UNITED STATES

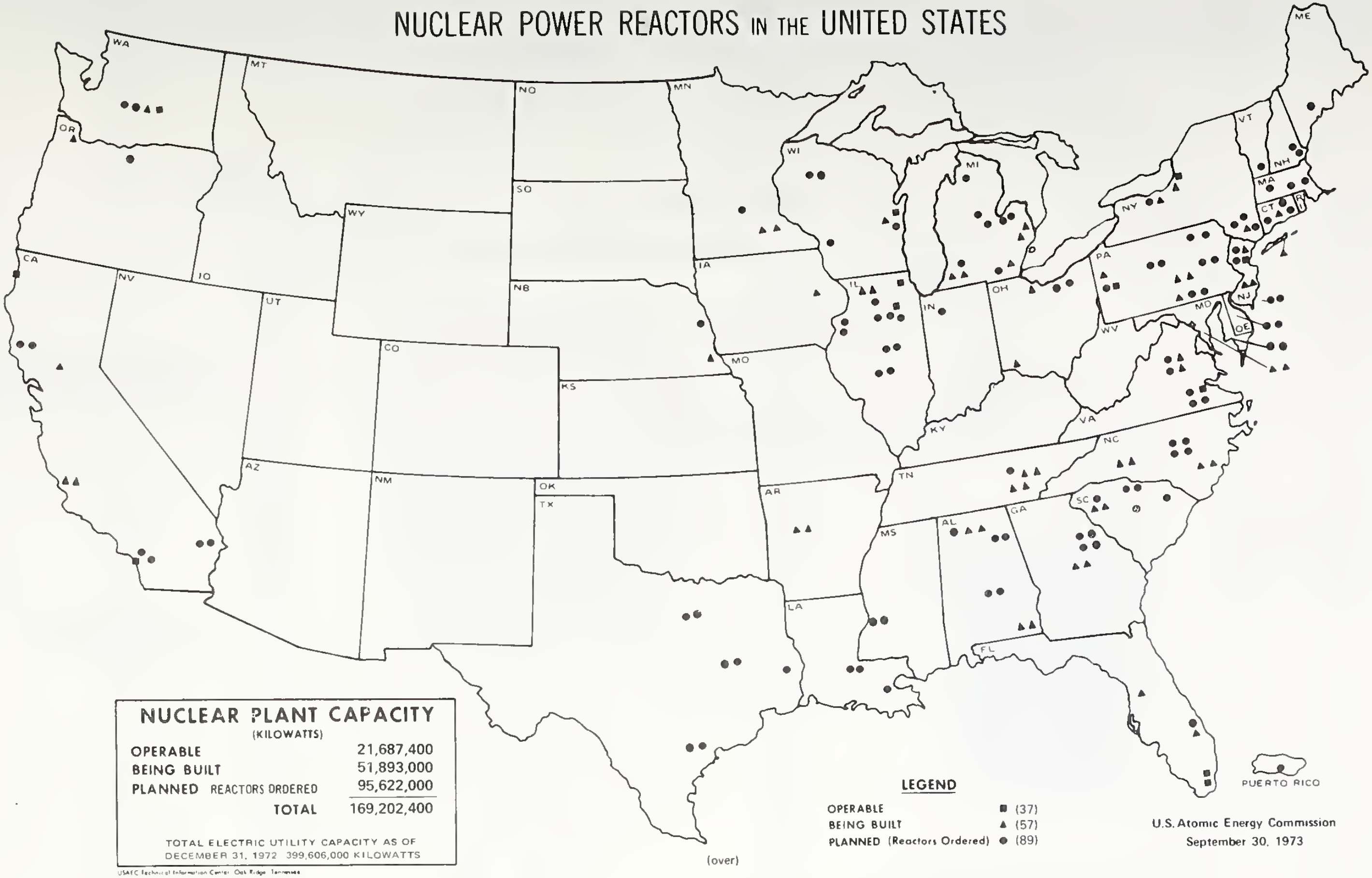


Figure 4.

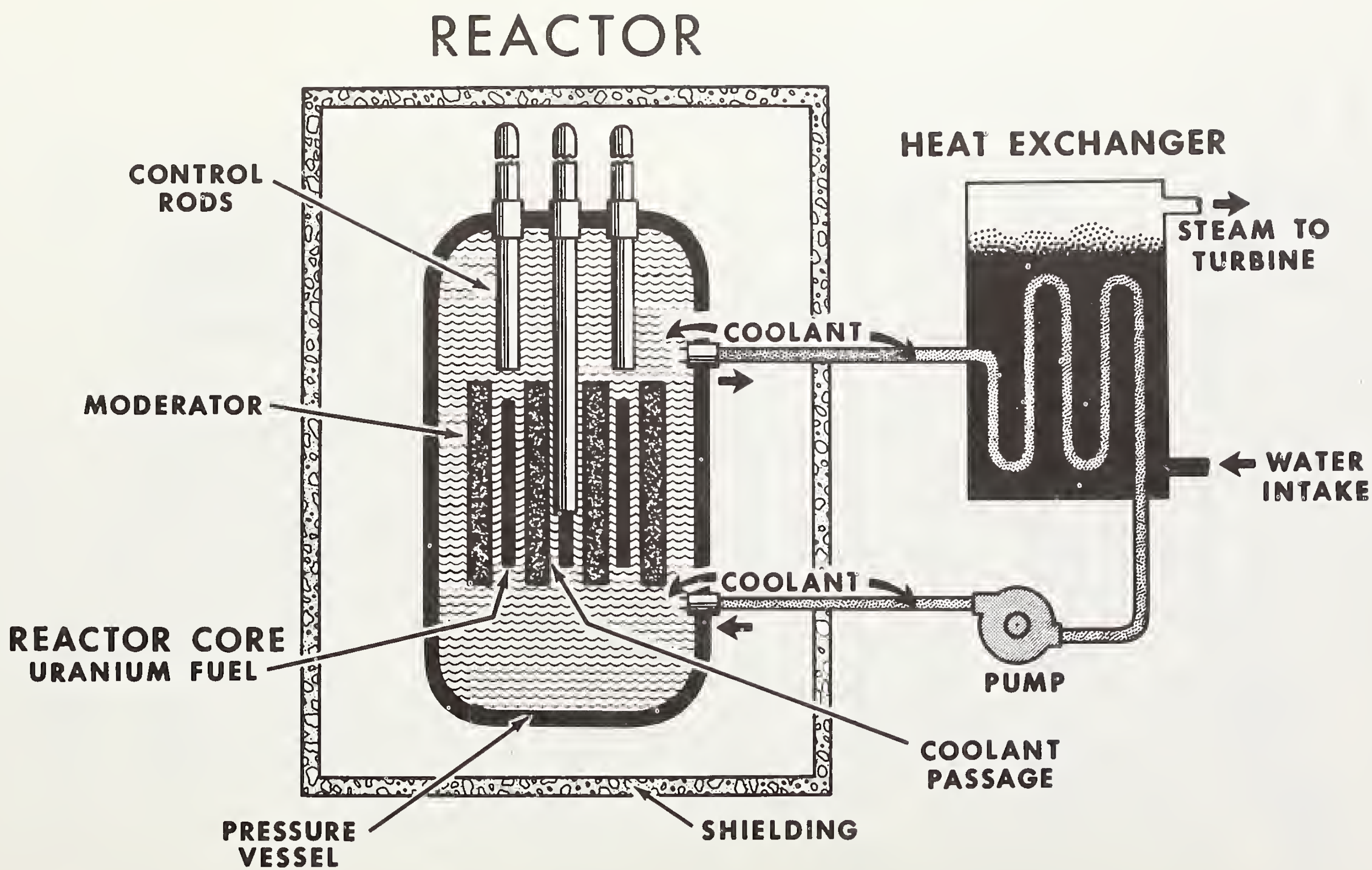
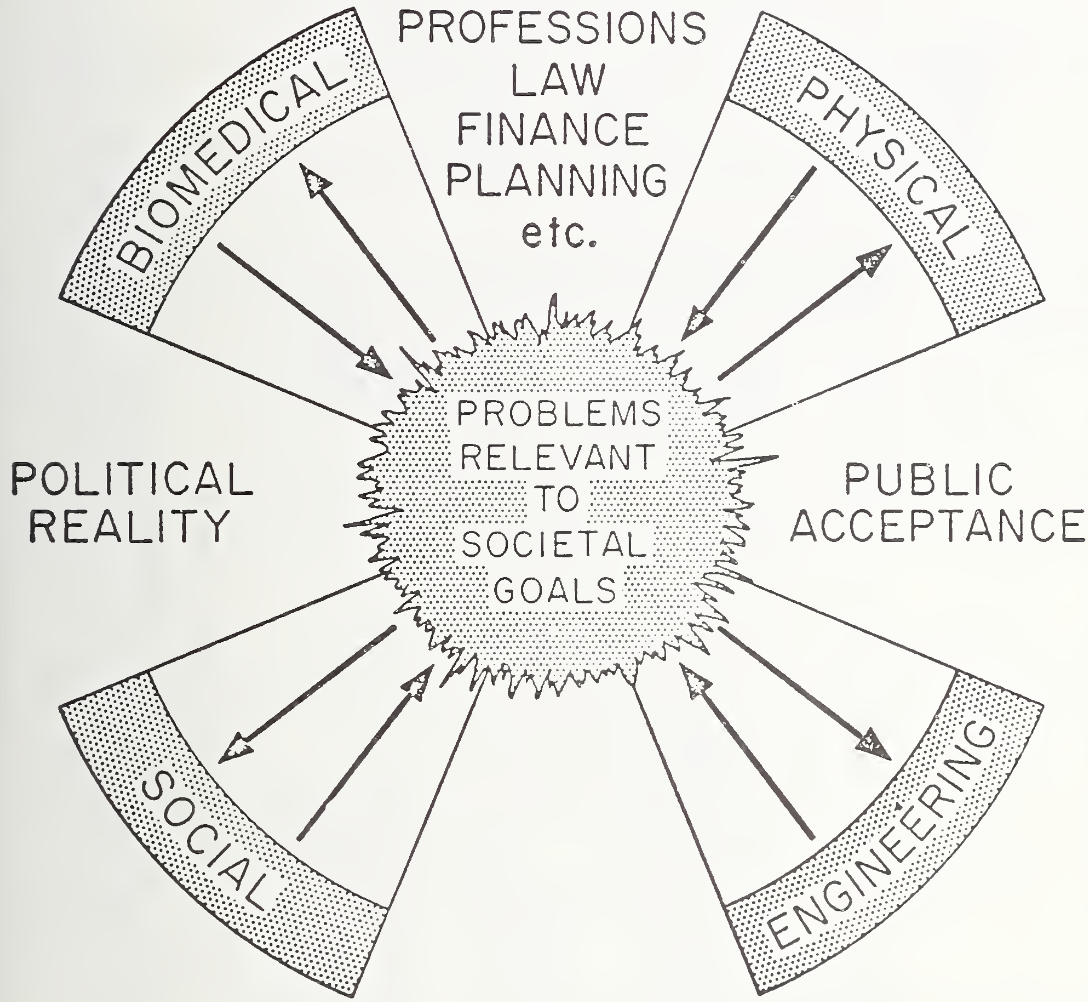

REACTOR
CONTROL RODS
MODERATOR
REACTOR CORE
URANIUM FUEL
PRESSURE VESSEL
SHIELDING
COOLANT
COOLANT
COOLANT PASSAGE
HEAT EXCHANGER
STEAM TO TURBINE
WATER INTAKE
PUMP

Figure 5.

INTERDISCIPLINARY APPROACH



Science in the Service of Man

Figure 6.

SOURCES OF GENETICALLY SIGNIFICANT RADIATION EXPOSURE (BEIR REPORT)

Source	Whole body exposure (mrem/year)	Genetically significant exposure (mrem/year)
Natural radiation		
Cosmic radiation	44	
Radionuclides in the body	18	
External gamma radiation	40	
Total	102	90
Man-made radiation		
Medical and dental	73	30-60
Fallout	4	
Occupational exposure	0.8	
Nuclear power (1970)	0.003	
Nuclear power (2000)	<1	
Radiation Protection Guide for man-made radiation - medical excluded to the general population (for reference)	170	

Figure 7.

ENERGY RESEARCH AND THE ELECTRIC POWER RESEARCH INSTITUTE

R. L. Loftness
(Electric Power Research Institute, Washington, D.C.)

The Articles of Incorporation of the Electric Power Research Institute define the broad purpose of the Institute as follows:

> "To promote, engage in, conduct and sponsor research and development with respect to electricity production, transmission, distribution and utilization, and all activities directly or indirectly related thereto."

The creation of EPRI stemmed from a number of considerations and was preceded by several activities that established the charter for its activities and its organizational structure. The concept of forming such an institute, with projected annual budgets in the $200 million range and an expected professional staff of 200 engineers, scientists and administrators, does not spring into being overnight. Such a concept is based upon experience, a sense of need, and careful study.

For many years the electric utilities, both public and investor-owned, have individually supported research and development programs. Many have joined forces to support specific projects, particularly in nuclear power. The investor-owned utilities have supported general R&D programs through the Edison Electric Institute and, in 1965, the Electric Research council was created for the purpose of funding R&D programs with support from federal, state, municipal, cooperative and investor-owned utilities.

Although the "energy crisis" has only recently attracted widespread public attention, primarily as a result of threatening shortages of fuel oil and gasoline, the potential for such a crisis has been long familiar to those charged with delivering energy to the public and those who contemplated the disparity in the growth rates in the curves of energy supply and energy demand. The impending crisis was apparent not only to those directly concerned with energy production but also to officials of the government. A federal report on "Energy Research and Development and National Progress", published in 1964, outlined the issues but did little to accelerate either energy R&D or national progress. Later in the 1960's, a growing public concern over the quality of the environment led to restrictions on the use of electric power plants whether hydro, nuclear, or fossil fuel. Not surprisingly these circumstances led to a pressing sense of need that a greatly expanded program to develop new and better methods for the generation, transmission, distribution, and utilization of electric power was essential.

The next step in the planning for this program was an assessment of the scope, direction, and priorities for the R&D effort. In the summer of 1970, the Electric Research Council established a Research and Development Goals Task Force of 17 utility executives and a Working Group of 28 utility engineers, to formulate such a program. With the assistance of other experts from the Electric utilities, associations, government agencies, equipment suppliers, universities and research organizations, this Task Force prepared a report "Electric Utilities Industry Research and Development Goals Through The Year 2000", that was published in June, 1971. The 30-year program suggested in the report represented an average annual R&D cost of $1.1 billion to be borne by the utilities, manufacturers and the government.

In its report, the R&D Goals Task Force also suggested that the Electric Research Council initiate an in-depth study to determine the best organization to implement the expanded research effort. This latter study led to the incorporation of the Electric Power Research Institute as a not-for-profit corporation in the District of Columbia in March 1972. By the end of 1972, Dr. Chauncey Starr, formerly Dean of Engineering at the University of California at Los Angeles, had been selected as the first president of EPRI.

EPRI Organization

The establishment of EPRI was, therefore, the culmination of dedicated efforts over a period of years by utility executives and engineers. These efforts provided EPRI a charter for the scope of its activities, an initial set of program priorities, some 70 on-going projects derived from the programs of the Electric Research Council and the Edison Electric Institute, and, importantly, a mechanism for funding the expanded R&D program. EPRI is indebted to all the individuals who participated in these efforts and these same managerial and engineering talents from the utility industry continue to have a vital role in the operation of the Institute.

The past ten months, during which EPRI has been transformed from an organization on paper to an organization in fact, can best be described as a period of transition--a period devoted to recruitment of senior personnel, selection of office facilities, transfer of operating functions, and review of key program areas. Under the direction of Dr. Starr and with the help of the members of the Board of Directors and the Advisory Council and the staff of the Electric Research Council and the Edison Electric Institute, much has been accomplished. Senior personnel joined EPRI during the summer months, the headquarters facility in Palo Alto and the office in Washington were activated in September, personnel and operating functions were transferred from the ERC and the EEI, and reviews were conducted in reactor safety, fusion, and coal conversion programs. Much remains to be done.

Organizationally, EPRI is governed by a 15-man Board of Directors. This board is comprised of 10 executives representing the investor-owned utilities and 5 from the public utility sector--including The National Rural Electric Cooperative Association, the American Public Power Association, the Tennessee Valley Authority, the Department of the Interior. (Fig. 1). The present chairman of the board is James E. Watson, manager of power for TVA and the vice-chairman is Shearon Harris, president and chairman of the board of Carolina Power and Light Company.

To assure the EPRI programs properly reflect the interests of the general public, members of the 25-man Advisory Council include seven from state regulatory commissions who were designated by the National Association of Regulatory Utility Commissioners and others representing a broad spectrum of professions outside the utility industry. (Fig. 2). Serving as temporary chairman of the Council is Emilio Q. Daddario, former Connecticut congressman and past chairman of the House Subcommittee on Science, Research and Development, who is now senior vice president of the Gulf and Western Group. The Council held meetings in June and September and will continue to do so on a quarterly basis.

Overall responsibility for the operations of EPRI rests with the president, Dr. Chauncey Starr. Reporting to the president are the directors of the four technical divisions as well as the directors for administration and the Washington office. (Fig. 3). The nuclear systems division (Fig. 4) under Dr. Milton Levenson, includes groups on nuclear safety, nuclear engineering and operations, and nuclear materials. Dr. Richard Balzhiser directs the activities of the fossil fuel and advanced systems division (Fig. 5) which will encompass a fossil fuels group responsible for programs for the direct use of fossil fuels as well as conversion technologies such as coal liquefaction and gasification; and an advanced systems group that is in charge of electro-chemical and electromechanical conversion and storage systems and the development of new energy sources--including fusion, solar and geothermal energy. The energy systems, environment and conservation division (Fig. 6), under Dr. Sam Schurr, is concerned with energy supply and demand studies, environmental impact studies, energy conservation, and systems planning and simulation. The fourth technical division, the transmission and distribution division (Fig. 7), for which a director has not yet been announced, covers all aspects of transmission and distribution development including bulk power substations and system security and control.

The staff of EPRI is expected ultimately to reach a level of about 200 professionals; about half will be permanent employees and about half will be engineers and scientists on temporary assignment from their regular positions with universities, industry, utilities, research institutes and the government. It is expected that this "temporary" staff will

provide a continuing influx of technical and managerial expertise, practical operating experience, and planning judgment. In addition, EPRI will employ, as the Electric Research Council and the Edison Electric Institute did in the past, a number of technical advisory committees who will provide advice and counsel on the technical merit of specific programs as well as on program direction and priorities. A senior Research Advisory Committee of about 15 members will provide advice on the over-all program, and 4 divisional committees will serve each of the technical divisions. These divisional committees will be served, in turn, by about 10 task forces and 30 sub-committees. Members of these committees will be based on nominations from the electric utilities.

EPRI Programs

The broad purpose of EPRI is to maintain an overview of, and participation in, all technical areas relating to electric power production, transmission, distribution and utilization, and to provide options that will enable the utility industry to move in a timely fashion in both traditional and new technologies.

In order to utilize available funds most effectively, cognizance will be needed of other on-going programs of the government and industry. As appropriate, cooperative programs will be jointly planned and managed with other organizations. EPRI's research and development program will be conducted largely on a contract basis, taking advantage of expertise and facilities wherever they exist--at universities, industrial laboratories, utilities, or government centers. As needed, EPRI may sponsor and operate one-of-a-kind test facilities that are not otherwise available.

The relative funding emphasis for the R&D programs for 1973-1974 is given in Fig. 8. Nuclear and fossil fuel programs each receive 27% of the budget, advanced systems, 16%, transmission and distribution, 20%, and systems analysis about 10%. The estimated availability of funds for the R&D program over the next few years is given in Fig. 9. Contributions to EPRI are based on an equivalent kilowatt-hour charge--0.067 mills/kwh in 1973, 0.10 mills/kwh in 1974 and a projected 0.125 mills/kwh in 1975 and 0.15 mills/kwh in 1976. The contribution levels for the year 1975-1976 are being used as planning levels but remain to be approved by member utilities. Fig. 10 also indicates two other aspects of the EPRI budget. Utilities may withhold twenty percent of their contribution to EPRI to fund local R&D of their own choosing and, in addition, about $21 million represents the annual contribution of the utility industry to the liquid metal fast breeder reactor demonstration plant program.

In addition to the projects taken over by EPRI from the ERC-EEI program, EPRI also has, as an initial basis for its program planning, the report prepared by the Electric Research Council's R&D goals Task Force. This report established four priority ratings for R&D programs ranging from "critically important" to "desirable". Among the projects rated critically important were: The achievement of the commercial fast breeder nuclear reactor by the mid-1980's; coal gasification; establishment in five to eight years of the scientific feasibility of power from controlled fusion; rapid improvement of the technology and equipment for the control of power plant stack emissions; development of better methods to utilize or dissipate waste heat; greatly improved methods for the underground transmission of large blocks of power; development of equipment to improve the environment including the electrochemical batteries and other components for electric transportation, and exploration of ways for the more efficient use of electric energy.

In general terms, the research and development goals identified in the R&D Goals Task Force report were:

- To produce, transmit and distribute electric energy in a manner compatible with a healthy and pleasant environment,

- To satisfy the increasing demands for electricity,

- To serve customers reliably,

- To keep the price of electricity as low as possible within a framework of adequate environmental protection and reliable service,

- To minimize the drain on natural resources,

- To increase the efficiency of the use of electric energy, and

- To facilitate the use of electricity to solve environmental problems.

Starting from this set of priorities and these objectives, it is now the responsibility of EPRI to formulate a greatly expanded R&D program that will not only answer the needs of the electric utilities but will also bear a proper relationship to the programs of the federal government and industry. In a programmatic sense, EPRI has a running start from the prior planning efforts of the ERC and the EEI as well as from the R&D projects that have been transferred to EPRI from these two organizations. These former ERC-EEI projects, involving an annual funding level of about $20 million, make up the bulk of the list of current EPRI projects given in Figures 10-13.

During the months of active existence of EPRI, a number of new projects have been initiated and a part of each bi-monthly meeting of the Board of Directors is devoted to the review of new project proposals. Some of the new projects have been of a program survey and planning nature, for example, studies were made during the summer months of the light water reactor safety program, of the fusion program, and of the coal conversion program. These reviews have included an assessment of federal and industry programs and the relationship of EPRI projects to those programs to avoid duplication of effort and to make certain that projects of interest to the electric utilities receive proper emphasis.

EPRI is not alone in its study of energy R&D needs and much can be derived from the energy R&D studies that have been completed (Fig. 14) and from those currently in process (Fig. 15). In fact, members of the EPRI staff - Drs. Starr, Levenson, Balzhiser, and Hill - have participated actively in a number of these past and present studies.

Of particular importance at present are two studies of the federal energy R&D program being conducted by the Atomic Energy Commission. One study, completed in September, recommended that $115 million be added to the current $886 million federal energy R&D budget. (Fig. 16). The AEC is also in the midst of another study to formulate plans for a $10 billion, five-year, energy R&D program. In this intensive study, the AEC has solicited program suggestions from industry and has received over 1100 proposals. These proposals are being considered by sixteen technical review subpanels--panels corresponding to the topics listed in Fig. 16. In addition, there are four workshop groups, comprised of outside experts who will make separate program recommendations. An overview panel, consisting of senior officials from various departments of the government will also review the program submissions and make recommendations. The chairman of the AEC, Dr. Dixie Lee Ray, has the responsibility of preparing the final report to the President. Finally, within the Executive Office of the President, the report will be scrutinized by the Office of Energy Policy and its Energy R&D Advisory Council as well as the Office of Management and Budget.

In addition to the energy planning activities of the executive branch of the government, there is an equally intense activity in the legislative branch. The list of twenty-four legislative proposals concerning the organization of energy R&D activities, given in Fig. 17, dates from September of this year. A number of additional bills have been introduced in the Congress since that time. Nor do these bills represent all the legislation of importance to utility operations--many others concerning land use, off-shore drilling, environmental regulations, plant siting, uranium enrichment, etc., have also been introduced and have tangential impact on energy R&D.

The conclusions reached in the energy R&D studies of the executive branch as well as the implementation of this activity through the legislative proposals under consideration, will have a significant influence on the planning of program and projects for EPRI. The

staff of EPRI will continue to work closely with the various federal agencies in laying out programs both of a cooperative and a complementary nature.

Through their support of EPRI, the electric utilities have undertaken to carry their share of the national energy R&D responsibility. The task is complex and the solutions are difficult, involving all sectors of our society and with major implications affecting our established way of life. In the past, the electric utilities have always met the challenge to serve the public. The creation of EPRI has been their response to the challenge of the present--and the future.

EPRI

BOARD OF DIRECTORS

James E. Watson	- Tennessee Valley Authority
Shearon Harris	- Carolina Power & Light Co.
Robert F. Gilkeson	- Philadelphia Electric Co.
Robert W. Gillette	- PUD of Grant County, Washington
Jack K. Horton	- Southern California Edison Co.
Charles F. Luce	- Consolidated Edison Co. of N.Y., Inc.
John M. McGurn	- Virginia Electric and Power Co.
William G. Meese	- The Detroit Edison Co.
Robert V. Phillips	- The City of Los Angeles, Water & Power
P. H. Robinson	- Houston Lighting & Power Co.
Thomas C. Shirley	- National Rural Electric Cooperative Ass'n.
Shermer L. Sibley	- Pacific Gas and Electric Co.
L. F. Sillin, Jr.	- Northeast Utilities
Stephen A. Wakefield	- U. S. Department of the Interior
Frank M. Warren	- Portland General Electric Co.

Figure 1.

EPRI

Advisory Council

George I. Bloom	- Pennsylvania Public Utility Commission
Harold Brown	- California Institute of Technology
Erwin D. Canham	- The Christian Science Monitor
Charles C. Coutant	- Oak Ridge National Laboratory
Emilio Q. Daddario	- Gulf and Western Engineering Group
Joseph L. Fisher	- Resources for the Future
Thomas L. Kimball	- National Wildlife Federation
James F. Mauze	- Missouri Public Service Commission
W. D. McElroy	- University of California, San Diego
Martin Meyerson	- University of Pennsylvania
Pat Moran	- Arkansas Public Service Commission
Bruce C. Netschert	- National Economic Research Associates, Inc.
William A. Nierenberg	- Scripps Institution of Oceanography
Arthur L. Padrutt	- Wisconsin Public Service Commission
Ruth Patrick	- The Academy of Natural Science, Philadelphia
Charles H. Pillard	- International Brotherhood of Electrical Workers
Elvis J. Stahr, Jr.	- National Audubon Society
Arthur C. Stern	- University of North Carolina
Joseph C. Swidler	- New York Public Service Commission
John P. Vukasin, Jr.	- California Public Utilities Commission
Henry C. Wallich	- Yale University
John G. Winger	- The Chase Manhattan Bank
Marvin R. Wooten	- North Carolina Utilities Commission

Figure 2.

EPRI ORGANIZATION

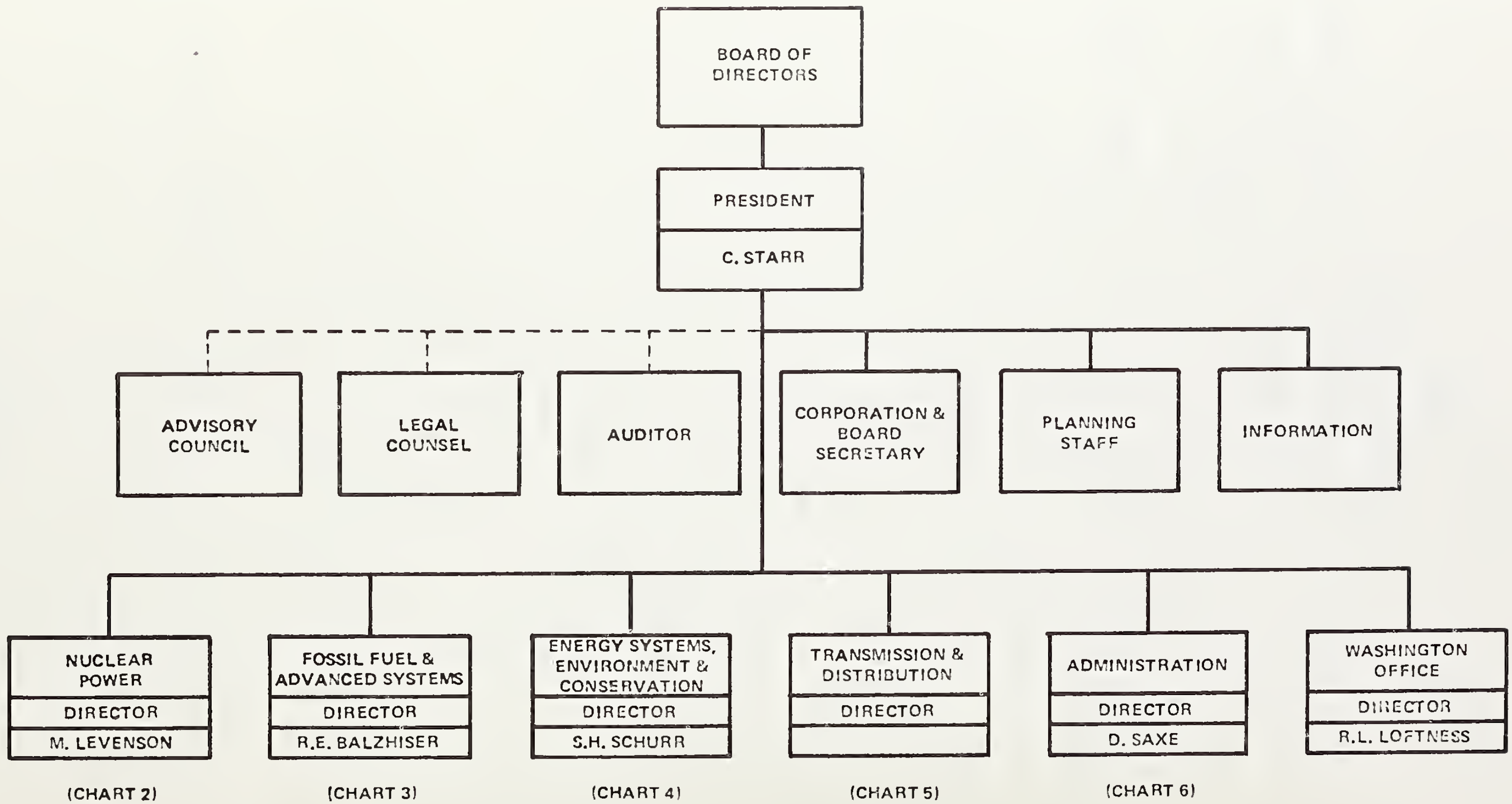


Figure 3.

EPRI NUCLEAR POWER DIVISION

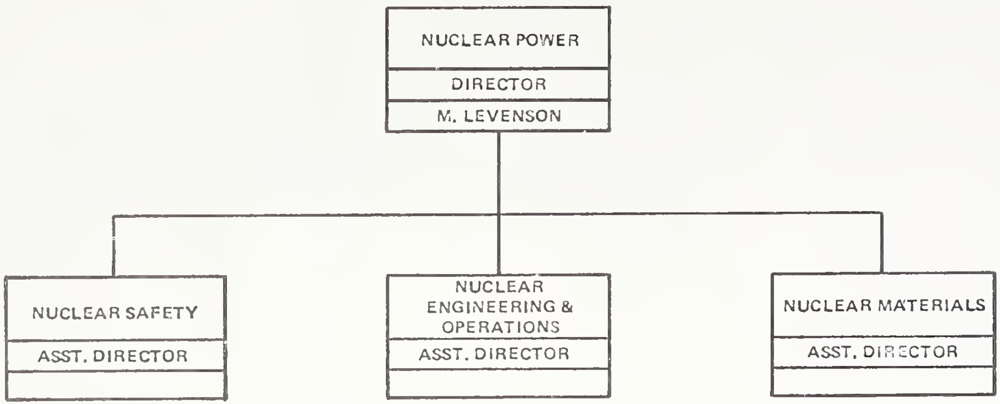
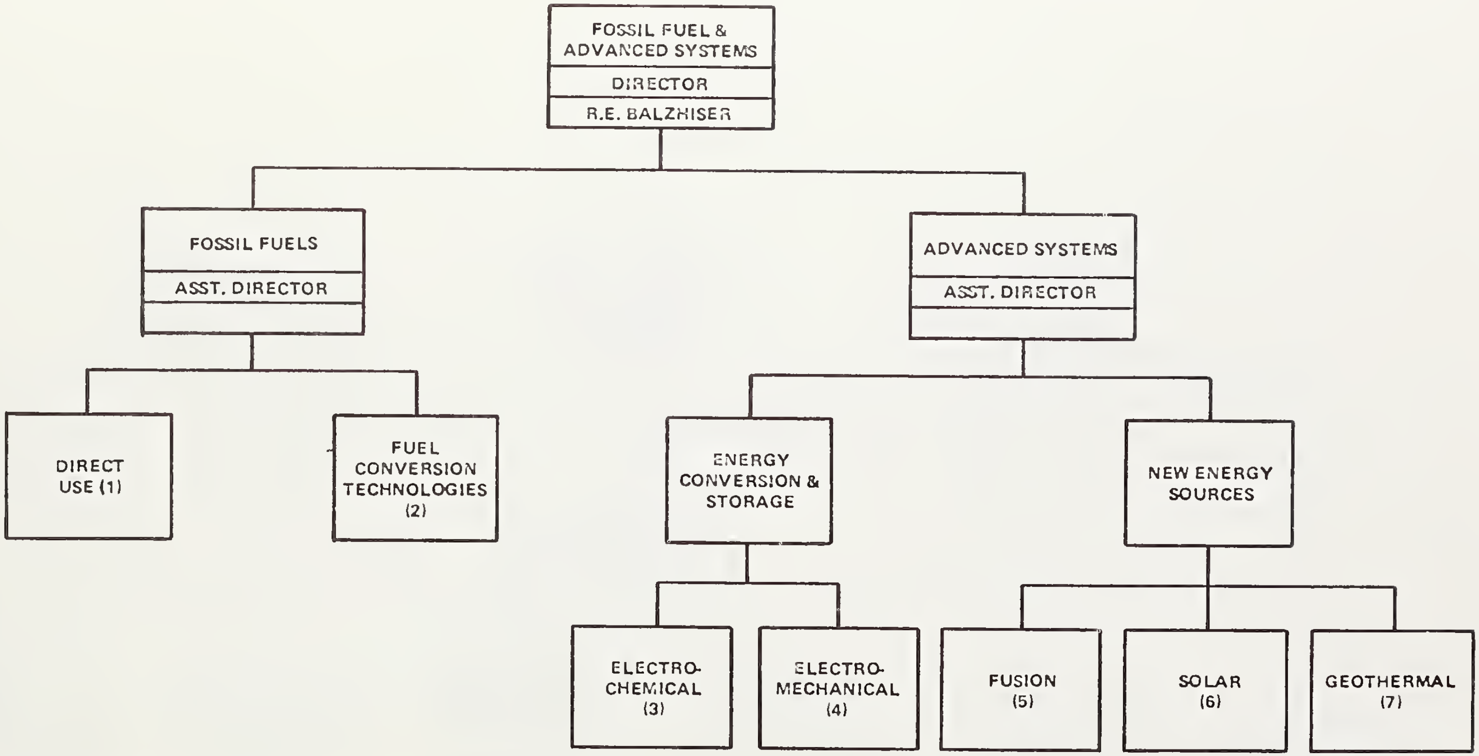


Figure 4.

EPRI FOSSIL FUEL & ADVANCED SYSTEMS DIVISION



NOTES: The activities of the groups under Dr. Balzhiser will include the following:

(1) Precipitators, Advanced Combustion, NOX Control, Mining, Waste Disposal, Coal Cleening
(2) Liquefaction, Gasitication (Low & High Btu), Oil Shale, in Situ Gasification
(3) Fuel Cells, Batteries, Hydrogen
(4) MHD, Turbines (Gas & Steam), k Cycle, Feher, Bottoming & Low Tempereture Cycles, Hydro, Superconductivity (Generators & Storege), Thermionics
(5) CTR, Laser
(6) Photovoltaic, Therm-electric, Wind Power
(7) Dry Steam, Hot Water, Hot Rock

Figure 5.

EPRI TRANSMISSION & DISTRIBUTION DIVISION

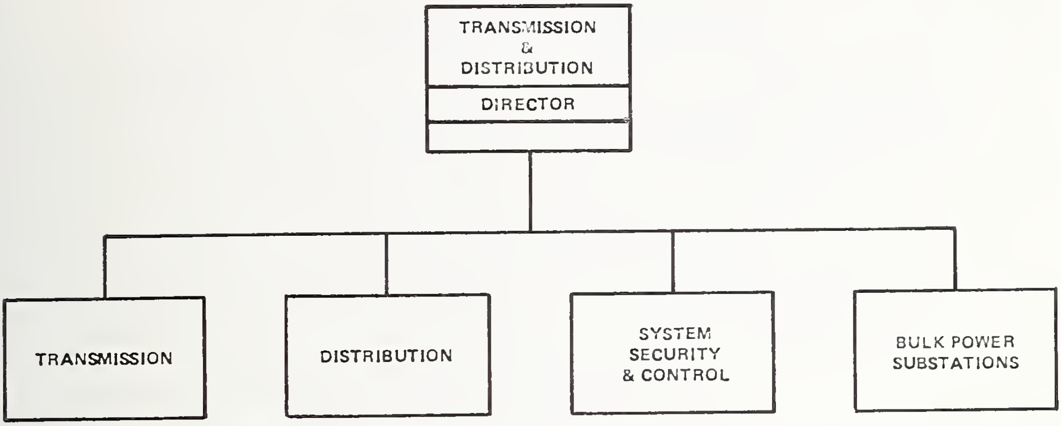


Figure 6.

EPRI ENERGY SYSTEMS, ENVIRONMENT & CONSERVATION DIVISION

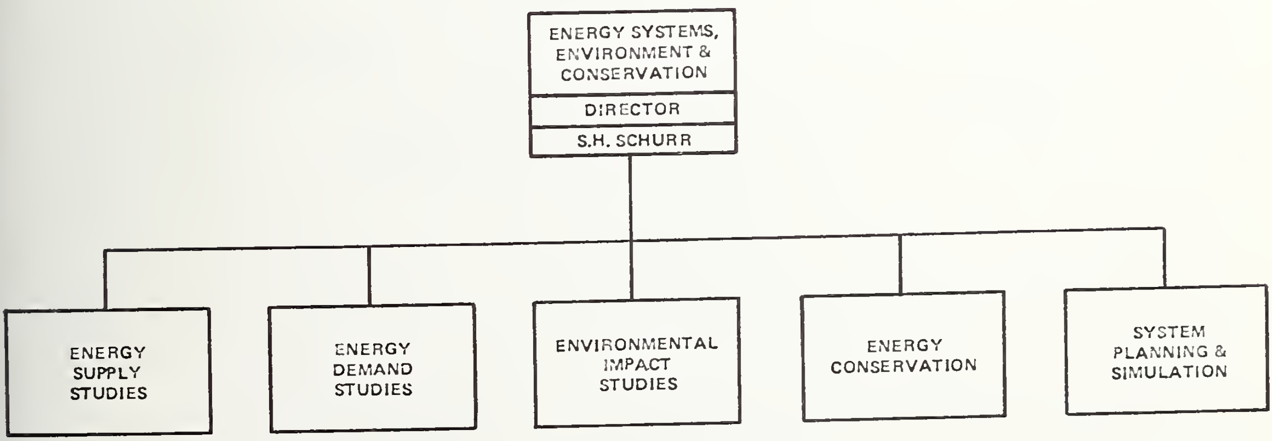


Figure 7.

EPRI Budget Distribution 1973-1974

Nuclear Programs	27%
Fossil Fuel Programs	27%
Advanced Systems	16%
Transmission and Distribution	20%
Energy Systems, Environment and Conservation	10%

Figure 8.

EPRI Estimated Fund Availability 1973-76

	1973	1974	1975	1976
Contribution Factor (mills/kw-hr)	0.0667	0.100	0.125	0.150
Funds (at 85% attainment) (in millions of dollars)	69	107	141	178
Less Local R&D Support (20%)	-13	-20	-27	-34
Less LMFBR Contribution	-20	-21	-21	-21
Funds Available to EPRI	39	65	91	121

Figure 9.

EPRI Approved Projects

Nuclear Safety

RP-132-1	Steam-Water Mixing	Combustion Engineering
RP-132-2	PWR Flecht Set	Westinghouse
RP-132-4	PWR Blowdown Heat Transfer	General Electric
RP-132-5	PWR Loss of Coolant	Combustion Engineering
RP-132-7	PWR Loss of Coolant Heat Transfer	Babcock and Wilcox
RP-132-8	PWR Transient Critical Heat Flux	MIT
RP-132-9	PWR Pump Characteristics	Combustion Engineering
RP-132-10	Cold Water Steam Mixing	Westinghouse
RP-132-11	Two Phase Flow	Battelle Northwest Lab.
RP-204-0-0	Analysis of Reactor Safety Research	Intermountain Technologies

Nuclear Engineering and Operations

RP-72	Use of Plutonium in Water Reactors	General Electric and Westinghouse
RP-84	Use of Plutonium in HTGR	Gulf General Atomic
RP-118	Plutonium Recycle Optimization	Nuclear Fuel Services
RP-130	Nuclear Reactor Core Benchmark Data	General Electric

Nuclear Materials

RP-131	Nuclear Fuel Densification	Battelle Northwest Lab.
PN-82	Welding Research Council Subscription	Welding Research Council

Figure 10.

EPRI Approved Projects

Fossil Fuels

RP 39	Stack Plume Opacity	Stanford Research Inst. & Public Health Serv.
RP 123	Solvent Refining of Coal	Southern Services
RP 138	Clean Fuel Demo Plant	LURGI
RP 200-0-0	Boiler Combustion Modifications	Esso Research & EPA
RP 202-0-0	Effects of Coal By-Products in Soil	Radian Corp.
RP 203-0-0	Economics of Low-BTU Coal Gassification	TVA
RP 206-0-0	Evaluation of Coal Conversion Processes	Univ. of Michigan
RP 207-0-0	Coal Catalysis Study	Libby Laboratories
PN 101	Stack Gas Information Center	Battelle Memorial Institute
PN 108	Definition of Combustion and Pollution Problems With Low BTU Gas	Institute of Gas Technology

Advanced Systems

RP 92	Superconductors in Large Synchronous Machines	MIT
RP 97	AVCO MHD	AVCO
RP 110	MHD Atmospheric Pollution	Stanford Univ.
RP 114	Fuel Cell Research	Pratt & Whitney
RP 96	Controlled Fusion	University of Texas
RP 108	Controlled Fusion	Cornell University
RP 113	Controlled Fusion	Princeton University
RP 115	Fusion Reactor Design	Gulf General Atomic
RP 109	Load Leveling Battery	ESB Company
RP 116	Lithium-Sulphur Battery	Atomics International
RP 127	Solid Electrolyte Battery	TRW
RP 128	Sodium Sulphur Battery	General Electric

Figure 11.

EPRI Approved Projects 1973

Transmission & Distribution

RP 68	UHV Transmission	General Electric
RP 104	HVDC Transmission	Bonneville Power Adm.
RP 106	Kilowatt-hour Standard	S. R. Houghton
RP 119	Mechanical Performance of Multiple Conductors	Alcoa Research Lab.
RP 129	Ecological Influence of Electric Fields	Westinghouse and Penn. State University
RP 133	Electrochemical Treeing In Cable	Phelphs Dodge Cable & Wire
RP 134	Coupling Capacitor Transformer for Metering	National Bureau of Standards
RP 78-1	Underground Transmission	Westinghouse
RP 78-2	Gas Dielectric Cable Insulation	MIT
RP 78-3	Cable Joint Simplification	Anaconda Wire and Cable
RP 78-4	Polymeric Paper Cable Insulation	Minnesota Mining & Man.
RP 78-6	Resistive Cryogenic Cable	General Electric
RP 78-7	Superconducting Cable System	Linde Div.-Union Carbide
RP 78-9	Cross-Linked Polyethylene Cable	Phelphs Dodge Cable & Wire
RP 78-10	Synthetic Laminar Insulated Cable	General Cable Corp.
RP 78-11	Cryogenic Cable Insulation	Stanford University
RP 78-12	750 KV Synthetic Tape Cable	Phelphs Dodge Cable & Wire
RP 78-13	Nitrogen Cryogenic Cable	Underground Power Corp.
RP 78-14	345 KV Capacitive Graded Joint	Phelphs Dodge Cable & Wire
RP 78-15	Simplified Splice for Extruded Insulation	Elaftimold Div.
RP 78-16	3-Conductor Compressed Gas Cable	High Voltage Power Corp.
RP 78-17	Evaluation of High Ampacity Potheads	G&W Electricity Specialty Corporation
RP 78-18	DC Cable	Okonite Co.
RP 78-19	550 KV Cable at 800 KV Forced Cooled	Westinghouse

Figure 12.

EPRI Approved Projects 1973 (continued)

RP 78-20	Detecting and Mapping Underground Obstacles	Stanford Research Institute
RP 78-21	Convective Cooling of Pipe-Type Cable	University of Illinois
RP 78-22	Superconductivity in Thin Films	Stanford University
RP 78-23-0	Forced Cooling Test Program	Jerome UTE
PN 20	Controlling Biological Deterioration of Wood	Oregon State University
PN 37	Systems Analysis of Underground Transmission Installation Methods	Arthur D. Little
PN 38	Optimization & Guide to the Design & Use of Gas Insulated Transmission Systems	ITE Imperial Corp.
PN 57	DC Prototype Link	General Electric
PN 60	New Methods & Chemicals to Control Tree Growth	U. S. Department of Agriculture
PN 68	Underground Electric Power Transmission Systems Environmental Impact Study	EDAW
PN 110	Reduction of Losses in AC Superconducting Lines	Stanford University
PN 111	An Extruded Dielectric Cable	General Electric
PN 112	Development of Extruded Solid Dielectric Underground Transmission Cables Rated at 138 KV through 345 KV	General Cable
PN 113	A New Class of Additives to Inhibit Tree Growth in Solid Extruded Cable Insulation	General Electric

System Security and Control

RP 90-3	Security Assignments (simulation approach)	International Business Machines
RP 90-4	System Equivalents	Systems Control
RP 90-7	Long-Term System Dynamics (digital simulation)	General Electric
RP 90-8	Long-Term System Dynamics (hybrid simulation)	University of Missouri

EPRI Approved Projects 1973

Energy Systems

RP 208-0-0	Development of a National Energy Evaluation System for Electric Power R&D Planning	General Electric
RS 1-0-0	APS Conference on Energy	American Physical Soc.
PN 114	Handbook of Energy Conservation	EPRI & United Kingdom Electricity Council Research Center

Environment

RP 49	Cooling Water Discharge	John Hopkins Univ.
RP 74	EPRI-NCA Air Pollution Research	Haxelton Lab., and Bituminous Coal Res.
RP 98	Biological Effects of Exposure to High Intensity Electric Fields	John Hopkins Univ.
RP 102	ASTM Air Quality Evaluation Methods	ASTM
RP 103	Environmental Effects of Herbicides	West Virginia University
RP 117	Trace Elements in Urban Aerosols	American Petroleum Inst. and NYU
RP 122	Trace Elements in Combustion Systems	Battelle Columbus
RP 201-0-0	Interaction of Sulfuric Acid Mist and NO_2	Haxelton Labs.
RP 205-0-0	Analysis of SO_2 Criteria	JRB Associates

Figure 13.

Selected Completed Studies Related to Energy R&D

1. Energy and the Environment: Electric Power--Council on Environmental Quality, 1973

2. Energy Conservation--Office of Emergency Preparedness, 1972

3. An Inventory of Energy Research--National Science Foundation, 1973

4. Systems Analysis Needs in Electric Power Systems--National Science Foundation, 1973

5. Energy Research Needs--Resources for the Future, 1971

6. The U.S. Energy Problem--Inter-Technology Corporation, 1971

7. Electric Utilities Industry R&D Goals through the Year 2000--Electric Research Council, 1971

8. Survey of Research--Electric Research Council, 1971

9. Energy R&D and National Progress--Interdepartmental Energy Study Group, 1964

Figure 14.

Selected Current Studies Related to Energy R&D

1. Energy R&D Study--AEC and other Federal Agencies

2. FPC Energy R&D Task Force Study--Federal Power Commission

3. OST Energy R&D Study--Office of Science and Technology

4. Energy-Related Regulatory Study--AEC and other Federal Agencies

5. U. S. Energy Outlook--National Petroleum Council

6. The Energy Policy Project--Ford Foundation

7. National Fuels and Energy Policy Study--Senate Committee on Interior and Insular Affairs

8. Comparative Risk-Cost-Benefit Study of Alternate Sources of Electrical Energy--AEC

9. Corps of Engineers Energy Task Force Study

Figure 15.

Federal Energy R&D Programs

		President's FY74 Budget	FY74 Increment (in Millions of Dollars)	FY74 Total
1.	Resource Assessment	7.3	1.0	8.3
2.	Mining - Coal and Shale	61.4	11.0	72.5
3.	Fuel Transportation, Distribution and Storage			
4.	Energy Transportation, Distribution and Storage	3.3	3.2	6.5
5.	Coal and Shale Processing and Combustion	78.0	38.7	96.7
6.	Conversion Techniques	5.8	4.0	9.8
7.	Enhanced Recovery of Oil and Gas	7.1	1.8	8.9
8.	Geothermal	4.1	7.0	11.1
9.	Solar	12.2	1.0	13.2
10.	Fission Reactors	517.0	7.1	524.1
11.	Fusion Reactors	91.4	7.3	98.7
12.	Conservation	9.2	7.3	16.5
13.	Advanced Automotive Systems	16.7	6.0	22.7
14.	Environment	85.0	17.4	102.4
15.	Multidirectional Research	4.4	0.6	5.2
16.	Energy Systems Analysis	5.3	1.5	6.8
	TOTALS	886.7	115.0	1003.4

Figure 16.

1973 Legislative Proposals for Energy R&D

1. A Council on Energy Policy--H.R. 921
2. A Corporation to Develop Synthetic Hydrocarbon Fuels--H.R. 220
3. Research for a National Power Grid--H.R. 1110
4. A Commission on Fuels and Energy--H.R. 1894
5. A Federal Power Research and Development Program--H.R. 4997
6. Research and Development for Automobile Propulsion--H.R. 5929
7. A National Energy Research and Development Act--H.R. 6038
8. Establishment of Mining and Mineral Research Centers--S. 263
9. A National Minerals and Materials Processing Institute--S. 453
10. A Corporation to Develop New Energy Sources--S. 454
11. A National Energy Resource Development Act--S. 1162
12. A National Fuels and Energy Conservation Policy--S. 2176
13. A National Energy Resources Advisory Board--S. 419
14. Electric Appliance Efficiency--S. 1327
15. Research into Possible Uses of Solid Wastes from Coal--H.R. 2110
16. Geothermal Research--H.R. 4413
17. Development of Nuclear-Powered Merchant Ships--H.R. 4217
18. A Energy Development and Supply Commission--H.R. 6194
19. A Joint Committee on Energy--H.R. 6313
20. Energy Reorganization Act--H.R. 9090
21. A Department of Energy--H.R. 9974
22. National Energy Research Center--H.R. 9133
23. Solar and Geothermal Energy--H.R. 9671
24. Coal Gasification Development Corporation--H.R. 9691

Figure 17.

THE ROLE OF THE PUBLIC IN THE EVALUATION PROCESS

G. Charnoff
(Shaw, Pittman, Potts & Trowbridge, Washington, D.C.)

Nuclear power has often been characterized as unique among industrial activities. Unlike other regulated industrial activities, it has been subject to pervasive regulation from its inception in 1954 as a non-governmental endeavor.

It is fashionable currently to malign the Congress as an inept institution of government. To its enormous credit however, the Congress anticipated the contemporary energy crunch. It stimulated and provoked the development of the only important source of energy available to us other than fossil fuel. But it also, from the beginning, recognized the risk benefit calculus of nuclear power. It, therefore, provided for a comprehensive system of safety regulation involving multiple levels of safety reviews.

It was in 1954 that Congress terminated the exclusive governmental monopoly of atomic energy established in the Atomic Energy Act of 1946. The 1954 Atomic Energy Act allowed the private ownership of nuclear power plants subject to license by the Atomic Energy Commission. Recognizing the complexity of such plants, Congress provided for two licensing reviews of such plants. In order to construct a nuclear power plant, the proposed owner must seek and obtain a construction permit from the AEC. The permit is granted only after a detailed technical review of the proposed design of the plant and after approval of the principal architectural and engineering criteria. Upon completion of the plant, a second and more detailed review is required before an operating license is issued authorizing fuel loading and operation of the plant. Four crude but quantitative measurements of the extensiveness of the AEC safety reviews are:

a. It takes applicants more than one year of effort by teams of engineers and scientists to prepare the safety analysis reports which accompany the applications for construction permits and operating license;

b. The safety analysis reports which are contained in standard 8-1/2 by 11 looseleaf notebooks require three to four feet of shelf space;

c. The AEC safety review by its multidisciplinary staff requires fourteen to eighteen months to complete; and

d. The AEC safety analysis report is typically about three-quarters of one inch thick.

To assure that the regulatory staff is adequately comprehensive and highly qualified, Congress in 1957 established the Advisory Committee on Reactor Safeguards. This Committee is popularly known by its acronym as the ACRS. It is composed of highly reputable and recognized experts from academia, industry and AEC's research laboratories. Performing much like a Ph.D. dissertation panel, ACRS reviews each application for a construction permit and for an operating license. Cognizant members of the regulatory staff and the applicants are questioned intensively by the ACRS on selected aspects of the design and plant construction. It provides its advice on each application to the Commission in a written report which, by law, is required to be made public. Thus, the Congressional scheme provides two highly competent technical reviews of each nuclear power plant prior to construction and two more such reviews prior to operation of each such plant.

As a further safeguard, and in recognition of the public's profound interest in atomic energy, Congress provided for a mandatory third level of review at the construction permit stage at a public hearing by an atomic safety and licensing board. The licensing board is composed of one lawyer member, who serves as chairman, and two engineering or scientific members. At the operating license stage any interested member of the public can request

and obtain a hearing by a licensing board to consider the specific matters he wishes to controvert.

With rare exceptions, the public hearings, in the period up to 1970, were essentially public education exercises. Virtually all construction permit and operating license applications were uncontested.

In 1970, the tumult witnessed elsewhere in the 1960's in American society caught up to AEC's public licensing proceedings. Opposition to license applications became the rule rather than the exception. Trial procedures and litigation tactics which had been developed and refined in other areas of legal controversy to determine factual matters were applied to test the validity of scientific and engineering judgment. Public intervenors used extensive prehearing discovery procedures and sought to conduct cross examination with respect to many of the myriad of technical decisions affecting the siting, design, and safe operation of nuclear power plants. AEC hearing processes and licensing boards, having been schooled in uncontested cases and civility, were initially unable to cope with the strains of the jungle warfare experienced in other areas of challenge to the establishment.

Coincidentally, the U.S. Court of Appeals for the District of Columbia paralyzed the entire process for more than a year. In July, 1971, the Court rendered its famous Calvert Cliffs decision. Liberally interpreting the National Environmental Policy Act (NEPA), the Court made all environmental matters appropriate for review by the AEC in connection with its review of construction permit and operating license applications. Formerly, the AEC's jurisdiction was limited to radiological health and safety matters. As a result of the Calvert Cliffs decision, the AEC had to take into account such matters as thermal effects of condenser cooling discharges, aesthetics, effects on wildlife, etc. In the summer of 1972, I litigated allegations that a once-through cooling system would destroy mysis relicta and that a natural draft cooling tower would cause significant adverse impacts on migrating birds which would impact on the cooling tower.

In any event the combined effect of public intervenors' opposition to nuclear plants and the Calvert Cliffs case, which gave the opponents unlimited issues to raise, was a stalemate of the licensing process. It was a deadlock which, at least, temporarily rewarded the opponents of nuclear power and which delayed the availability of power generation from a number of power plants.

Thoughtful observers began questioning the role of public intervenors and the purpose of public hearings in a decision-making process involving many highly sophisticated nuclear safety and environmental matters. Do public intervenors represent the public interest or just a small sector of the public? Do the electric companies represent a larger segment of the public interest which is vitally interested in a reliable, safe, and economic supply of energy? Are complex technical matters best resolved with the aid of lawyers skilled in the adversary process? To what extent should such technical matters be left to the experts? How do we keep the experts honest and aware of conflicting opinion? Have we overly complicated the decision-making process? And so on.

Alfred Marshall once wrote, "Government is the most precious of human possessions, and no care can be too great to be spent on enabling it to do its work in the best way." He warned that government "should not be set to work for which it is not specially qualified under the conditions of time and place."

Based on the experience of the last three years, we may reasonably inquire whether the AEC public hearing process is not an example of a governmental task for which it is not specially qualified. In a decade of mounting public concern for environmental protection, a decade of retreat from representative democracy in favor of maximum public participation in decision making, it is clear that we have succeeded in constructing issues which pose incompatible demands on our decision makers. One prominent observer of the political evolution in America, Aaron Wildavsky, Dean of the Graduate School of Public Policy at the University of California at Berkeley, recently wrote that "the incompatibility of policy

demands is a manifestation of a more general withdrawal of sovereignty from government in America."

How has the AEC reacted to the different and fast changing demands placed upon it? Dean Wildavsky warned that governments faced with incompatible policy demands will push form over substance. While such a charge cannot yet be fairly leveled at the AEC, it is clear that the AEC has tended to avoid making some fundamental policy decisions wherever possible.

Attorneys for license applicants and for public intervenors have urged definition of the role of public intervenors. Is it the role of public intervenors to bring facts in their possession to the decision makers within the AEC or is it their role through extensive discovery and cross examination to perform a de novo review of both the license application and of the performance by the AEC staff of its regulatory responsibilities? A recently concluded hearing spent several days considering a contention by an intervenor that the AEC's spot or selective inspection procedure is inadequate although no allegation and no evidence was presented attempting to show that the facility at issue was not properly constructed. Most public intervenors opt for the second formulation of their role. I believe the first and more limited formulation is more appropriate.

In the summer of 1972, the AEC restructured its rules of practice. The new rules appeared to tilt in favor of the more limited formulation of the role of public intervenors. Members of the public who wish to participate as parties in AEC public hearings are required to file a petition for leave to intervene. The petition, to be acceptable, is required to set forth specific contentions, the bases for the contentions and a supporting affidavit. Thus it appeared that public intervenors would have to demonstrate at the outset that they have some information to present to the decision makers which warrants holding a public hearing.

In practice, however, the new regulations have not been applied with any rigor by the AEC staff or by AEC licensing boards. While a petition without any contentions or a petition simply alleging that the proposed plant will be unsafe or environmentally unacceptable will be denied, the AEC apparently will grant a petition if it alleges that some portion of a plant is unsafe in some respect or that a portion of the plant will cause some environmental concern. Thus AEC has accepted a contention that the cooling towers at a proposed plant will cause a hazard to the public health and safety. AEC will say that such a contention only minimally meets the requirements of the new regulations but it will grant the petition on the basis of such a contention. The requirement of a "basis" for each contention has been ignored by the AEC.

More recently in two different and apparently conflicting Atomic Safety and Licensing Appeal Board Decision, the Commission has approached this central issue. In one case the Appeal Board stated that a public intervenor urging denial of a license has the burden of going forward with evidence to support his contention. This is less of a requirement than the burden of proof which is imposed on license applicants. Presumably, if an intervenor cannot or does not go forward with evidence on his contention, then the license applicant need not meet his burden of proof. This requirement of going forward is a reasonable one and would distinguish between those public intervenors who have some fact or expert judgment to offer for consideration by the ultimate decision makers and those public intervenors who seek to prevail only by delay. However, within weeks after that decision, the Appeal Board in another case wrote that a public intervenor can proceed solely by cross examination of the witnesses presented by the Applicants and the Regulatory Staff. We are left to wonder at the role of public intervenors.

The failure of the Commission to give its licensing boards definitive guidance on this matter is quite serious. Because they are professionally fearful of being reversed on appeal and because the reversal of a restrictive ruling on the role of an intervenor could invalidate a favorable ruling on the licensing of a plant, the licensing boards and applicants' attorneys tend to be overly liberal in construing the role of intervenors. The consequence of all this is protracted proceedings which are costly to applicants and

to the public interests served by them.

While citizen input in a free society is obviously pertinent to the location and the need for a power plant, it is not clear to me that protracted public proceedings serve any public interest. Although Dostoevsky in Notes from the Underground observed that "man is a frivolous and incongruous creature, and, perhaps, like a chess player, loves only the process of the game, not the end of it," those of us who have participated in AEC proceedings have yet to perceive that a cost-benefit evaluation of the public hearing process justifies protracted proceedings. Definition of the role of the public intervenor is essential to disciplining a process which has so many variables to consider. Similarly, it is clear to me that, as a society, we cannot afford to iterate and reiterate the same contentions with respect to each power plant that is proposed for construction and operation as if each plant was the first of a kind. We are challenged, therefore, to find means to fairly incorporate in each case past deliberations and decisions on the same matters. To some extent public intervenors must be compelled to accept responsibility for decisions in prior cases which were litigated by the public intervenors.

Two weeks ago, Dr. Dixy Lee Ray, Chairman of the U.S. Atomic Energy Commission, stated in her speech to the Atomic Industrial Forum and the American Nuclear Society that:

> "We do have an energy crisis and public acknowledgment of this fact is the necessary prelude to decisive action. In taking decisive actions, however, there are no easy answers and certainly no absolutes - no guaranteed solutions."

Decisive actions are required if we are to avoid making inaction a decisive action. As science teachers in an age of ecological concern, you have a splendid opportunity to teach your students the maxim espoused by Dr. Barry Commoner. He contends, as you know, that ecologically speaking, there is no such thing as a free lunch. Ecologically speaking, inaction is an action and has consequences. If we are to avoid the evils of the "papa knows best" system, the public must be allowed to participate in decision making. On the other hand we cannot countenance a system which disregards expert and competent opinion in favor of the uninformed fear mongers; we should attempt to distinguish those issues on which the public should be heard from those where only expert judgment should be applicable. The public intervenor's role should be distinguished in the two situations. In any event, it should be clear that the role of the public intervenor is to present facts in his possession or judgments to the decision maker; it is not to deadlock the decision making process by redoing the whole staff review process.

ASSESSING ENVIRONMENTAL EFFECTS, THE RISK AND BENEFIT CONCEPT

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Geologists have concluded that the earth was formed more than 3 billion years ago. Since the advent of primitive man some 1.8 million years ago, he has steadily increased his domination over his environment and life on earth. Now man faces the serious possibility of extinction by the destruction of the very environment that has supported his rise to evolutional supremacy. Man requires air, water and organic food subsistence such as meat and plants to survive. All animals (including man) (fauna) and plants (flora) depend directly or indirectly on energy from the sun. All organisms require nutrients also. Animals obtain their energy from food substances whereas plants and phytoplankton procure theirs from the sun by photosynthesis. In Figure 1 we see a simplified nutrient - energy diagram. Here we see a chain linkage arrangement related to the flow of nutrients and energy through the basic ecological system including man. So, obviously it is possible to alter or destroy a link in a biological community which is not a direct source of food for man but which, if destroyed, will result in the loss of a food source. Another thing we see is that plants are an essential part of any food chain and of life itself, irrespective of the Oxygen-Carbon dioxide cycle between animals and plants.

We know that, primarily since the industrial revolution, man has continually degraded his environment. From an ecological viewpoint, man has been degrading his American land areas since the Pilgrims first landed on the American shores. At that time they viewed from their ships an expanse of endless, fully developed forests. Now in the Eastern one-third of the United States over 70% of all land is in various stages of recovery from manipulations by man. It takes tilled land areas fifty to one hundred years to return to its initial fully developed forest state.

Industry, agriculture and mining have played major roles in altering our ecological environment.

The basic criticism to be levied at both industry and agriculture is that no consideration has been given to the fact that all of our air, water and land resources are limited and unless restoration is undertaken at the same time that our resources are used then there will be a steady degradation.

Let us dramatize our need for concern for our environment with an example of how man can cause the earth to die as depicted by Dr. Jacques Cousteau. The ocean occupies 70 per cent of the earth's surface. If the oceans of the earth should die - for example from the deposition of a thin polluting organic and/or oily film - it would be the final as well as greatest catastrophe for man and all the other animals and plants with whom man shares this planet. The thin film would of course cut off most of the supply of oxygen and carbon dioxide from the atmosphere and cause death to most oxygen and carbon dioxide consuming flora and fauna in the ocean.

We quote as follows:

> "To begin with, bereft of life the ocean would at once foul. Such a colossal stench born of decaying organic matter would rise from the ocean wasteland that it would of itself suffice to drive man back from all coastal regions. Far harsher consequences would soon follow. The ocean is earth's principal buffer, keeping balances intact between the different salts and gases of which our lives are composed and on which they depend. With no life in the seas the carbon dioxide content of the atmosphere would set forth on an inexorable climb. When this CO_2 level passed a certain point the "greenhouse effect" would come into operation: heat radiating outwards from earth to space would be trapped beneath the stratosphere, shooting up

sea-level temperatures. At both North and South Poles the icecaps would melt. The oceans would rise perhaps 100 feet in a small number of years. All earth's major cities would be inundated. To avoid drowning one third of the world's population would be compelled to flee to hills and mountains, hills and mountains unready to receive these people, unable to produce enough food for them. Among many other consequences of the death of the oceans the surface would become coated with a thick film of dead organic matter, affecting the evaporation process, reducing rain, and starting global drought and famine.

Even now the disaster is only entering its terminal phase. Packed together on various highlands, starving, subject to bizarre storms and diseases, with families and societies totally disrupted, what is left of mankind begins to suffer from anoxia-lack of oxygen-caused by the extinction of plankton algae and the reduction of land vegetation. Pinned in the narrow belt between dead seas and sterile mountain-slopes man coughs out his last moments in unutterable agony. Maybe thirty to fifty years after the ocean has died the last man on earth takes his own last breath. Organic life on the planet is reduced to bacteria and a few scavenger insects."

Perhaps this is an overly-exaggerated picture of what can happen on our earth, but I am hopeful that it does stimulate some concern.

Let's now look at nuclear and conventional power plants. Figure 2 shows an early generation nuclear power plant located at Oyster Creek, New Jersey. I am showing this figure to illustrate that both nuclear and conventional power plants have direct contact with the environment. Here we show the configuration for this particular power plant which has a cooling channel that provides a source of water for the reactor coolant system. This is called a once-through type nuclear reactor plant as far as the coolant system is concerned. Approximately 450,000 gallons of water per minute flows through this plant as a source of coolant. In addition, there is an additional 760,000 gallons per minute flowing through a by-pass channel to provide dilution such that as the channel continues out and enters into the bay on the coast of New Jersey the water is diluted and consequently proportionally decreased in temperature. We also see, of course, that there are other means in which it has contact with the environment. It has a stack which emits gaseous effluents with some of these effluents being radioactive. Each of these pathways to the environment are also therefore pathways to man himself and to our ecological cycles that we have in the environment.

Congress, as a result of a national environmental interest, passed an act in 1969 - the National Environmental Policy Act. I want to read a section of this so that you can clearly see the wording and the interest that is specified in this bill. Part of the text goes as follows:

"...it is the continuing responsibility of the Federal Government to use all practical means, consistent with other essential considerations of national policy, to improve and coordinate Federal plans, functions, programs, and resources to the end that the Nation may;

"(1) Fulfill the responsibilities of each generation as trustee of the environment for succeeding generations;
"(2) assure for all Americans safe, healthful, productive and esthetically and culturally pleasing surroundings;
"(3) attain the widest range of beneficial use of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences;
"(4) preserve important historic, cultural, and natural aspects of our national heritage and maintain, wherever possible, an environment which supports diversity and variety of individual choice;
"(5) achieve a balance between population and resource use which will permit high standards of living and a wide sharing of life's amenities; and
"(6) enhance the quality of renewable resources and approach the maximum

attainable recycling of depletable resources."

In other words the resources that we can renew we should maximize utilization, for example, timber is a resource we can restore by planting new trees as trees are cut - this is a renewable source. The second aspect of part (6) above is that wherever possible with depletable resources - and fossile fuels are examples of depletable resources - we should provide for recycling. But unfortunately we cannot recycle fuels once they are consumed so that fossile fuels are a depletable resource. Clearly as specified in NEPA then, we have an obligation to consider our environment. It also must be clear that this is going to involve an extremely complicated task of making decisions and judgments regarding what is best in terms of use of our national resources and in particular providing energy for our nation with a fair consideration of the environment.

A method called cost-benefit analysis has been used to some extent to assist this task. The cost-benefit analysis is a relatively new concept to the average individual - at least on a formal basis. This technique has been applied for some years by scientists at the National Science Foundation to assist in the decision-making for allocating our public funds for public welfare. The average individual frequently both consciously and subconsciously weighs the various trade-offs available in instances in a broad range of cases from the brand name of suit he wears to how he will spend his vacation. Usually the trade-offs for individuals are monetary cost versus the personal and family benefit to the individual. It is recognized that this technique - the cost-benefit analysis technique - may eventually have to be applied to many other socio-technical systems other than associated with our environment as our life on this earth becomes increasingly more complex. There is scepticism, however, by many as to whether the complex factors effecting our society can ever be assigned numerical values to the extent that they can be used to guide decisions regarding the degree of control that should be optimumly exercised over various socio-technical systems. Certainly one can argue that it will be undesirable to apply the cost-benefit concept to trivial questions such as, for example, whether a tree should be removed in a city park to provide space for a water fountain. There are also political and emotional aspects in most sociological decision making that, in many instances, would nulify any quantitative conclusions obtained by a cost-benefit analysis.

The idea of the method is to weigh all benefits against all costs (and risks) to determine the most desirable alternative. First let's look at the various combinations of benefits and costs that can be experienced. Not all things benefit or cost all people in the same way in our society. There are socio-technical systems which adversely effect individuals but benefit large population groups. An example is condemnation of an individuals land for new highway construction. On the other hand, private ownership of handguns for the protection of the individual does cause thousands of deaths to the general population each year. Then, individuals can benefit at the expense of the public. Snow skiing is a simple case where both the costs in terms of risk of injury and the benefits are shared by the same individual.

Here we come to another fundamental question in cost-benefit analysis. Should we apply special considerations to whether a cost (risk) is voluntarily or involuntarily imposed. For example, do we have the right to require an individual to use a safety belt on an airplane when it only involves risk to himself. Our society has determined that we do have that right. Yet there is no law against stock car racing, or smoking or mountain climbing. Another point is that our society is not always consistent.

NEPA therefore requires the consideration of environmental aspects associated with all areas of our society - nuclear and conventional power sources being no exception.

Let's look at what ways a nuclear power plant can provide benefits and impose costs or risks - in other words, what factors enter into an environmental cost-benefit analysis for power plants.

A nuclear power plant has impact on the environment in the sense that

1. It requires land at the plant site itself - both nuclear and conventional power plants consume in some cases up to 4,000 acres of land - so that this is a large consumption of land. It requires, in many cases, many miles of transmission lines also.

2. It emits effluents, chemical effluents from both the conventional and nuclear plant. From a nuclear plant we also have radiological emissions, although from a fossile fuel plant we have natural radioactivity contained in the coal being emitted also. And finally we have thermal emission, in the sense that the coolant water that is ejected is always at elevated temperatures.

3. It consumes water - even with a closed loop system with coolant towers, for examples, both a conventional and a nuclear plant will consume on the order of thousands of gallons per minute of water.

4. It generates large amounts of waste and thus creates waste disposal problems.

5. It causes social and economical effects within the community.

So we see that we have these direct effects. Now, the next question is, in what way can these contacts with our environment effect the ecology of the environment locally, regionally or nationally. Professor Jenson will discuss this in considerably more detail, but as we showed in Figure 1, the nutrient and energy flow diagrams, the basic source of energy being transferred into two plants by the process of photosynthesis. We pointed out that through the chain man is a recipient of those nutrients and energy from many links. We also indicated a breakage in this chain could lead to very serious consequences. For example, without plant life there would be no actual food chains directly to man, so that we are directly dependent on this link in the chain. The point I am making is that there are these linkages which exist on a local, national and worldwide scale. In the selection of a power plant site, one has to consider the ecology of the site and examine how the ecological chains operate in the site region. In particular we need to know where, for example, the ecology is presently being strained, and if the construction of a plant at that site could have a disastrous effect on the site.

With NEPA and in particular with the present requirement that a complete and thorough cost-benefit analysis study be performed for the construction of each nuclear power plant before the license for construction is issued and before the license for operation is issued, then extensive studies are being performed of the effects on the environment as a proposed nuclear power plant site. Figure 3 shows in diagram form the various pathways for radiation exposure of organisms other than man. The gaseous effluents contain radioactive material. This again is an earlier generation plant which emits considerably more than the present generation, but we do see the pathways that both gaseous and liquid effluents can follow to escape from the plant. In each analysis it has to be demonstrated that the amounts and the concentrations that are involved are completely safe within safety factors on the order of 100 as related to what we consider acceptable environmental levels.

In Figure 4 we show the various pathways to man for the same plant. The point I am making with these illustrations is that these analysis are made and very carefully examined to determine the various ecological pathways not only for radiation but for chemical effluents as well - with the end result being the determination of any adverse effects to the environment.

The A.E.C. then asks, in the Environmental Report that has to be submitted, that several basic questions be answered. One being "Is the electrical energy really needed now?" I must clarify that because of the point that was made by Dr. Lawson that a plant has to be planned 10 years before actual electricity is realized. The utility has to demonstrate without any doubt whatsoever, that, according to realistic projected energy demands, this plant is needed and therefore it should be constructed. Secondly, the A.E.C. asks "What are the environmental costs in the construction of the plant?" Thirdly, "What are the benefits?" I have mentioned some of the environmental costs. To balance the costs, the benefits that are bonified in the cost-benefit analysis are 1.) the electrical capacity 2.) the direct

steam capacity, 3.) the tax income for the local area, 4.) increased jobs, 5.) land which is developed into recreational areas within the site itself and lastly 6.) a program of site ecological development instituted and financed by the utility company.

What are some of the basic problems in applying this cost-benefit analysis? One fundamental problem is that it is extremely difficult to try to balance various factors when they basically do not have common units. For example, the electrical capacity can be quantified in terms of megawatt hours of electricity. Land consumption is quantified in acres, effect on marine life in the environment quantified in pounds of fish destroyed, so that it is difficult in doing the cost-benefit analysis to come up with an equation. Ideally we would like to have everything in the same units instead of apples and oranges, for example, and thus be able to equate the two. The last, but most important problem, is developing a method of evaluating the environmental effects that extrapolates to the long range effects on the ecological systems that are involved. Professor Jenson will discuss how we look at this problem.

NUTRIENT AND ENERGY FLOW

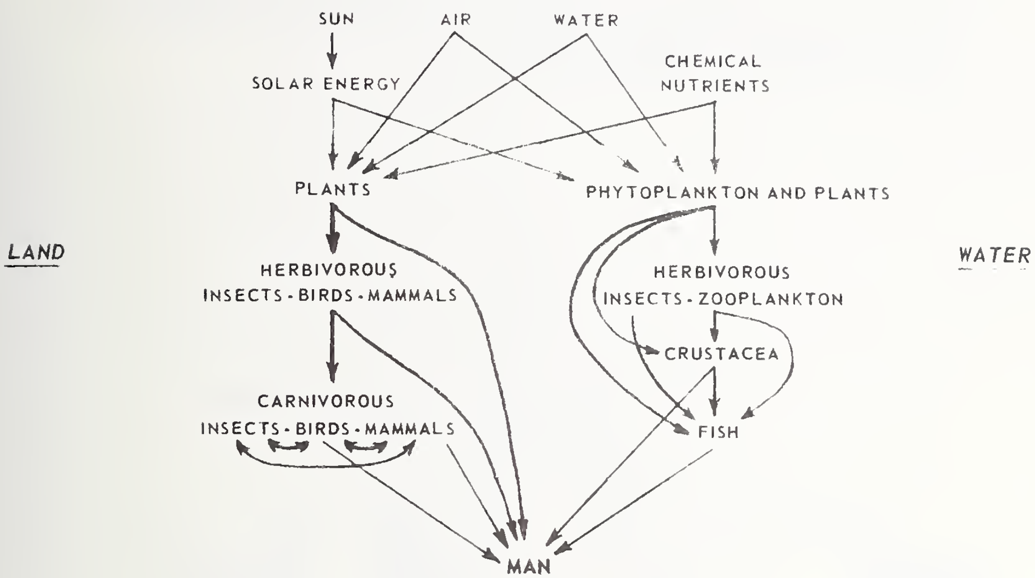

Figure 1.

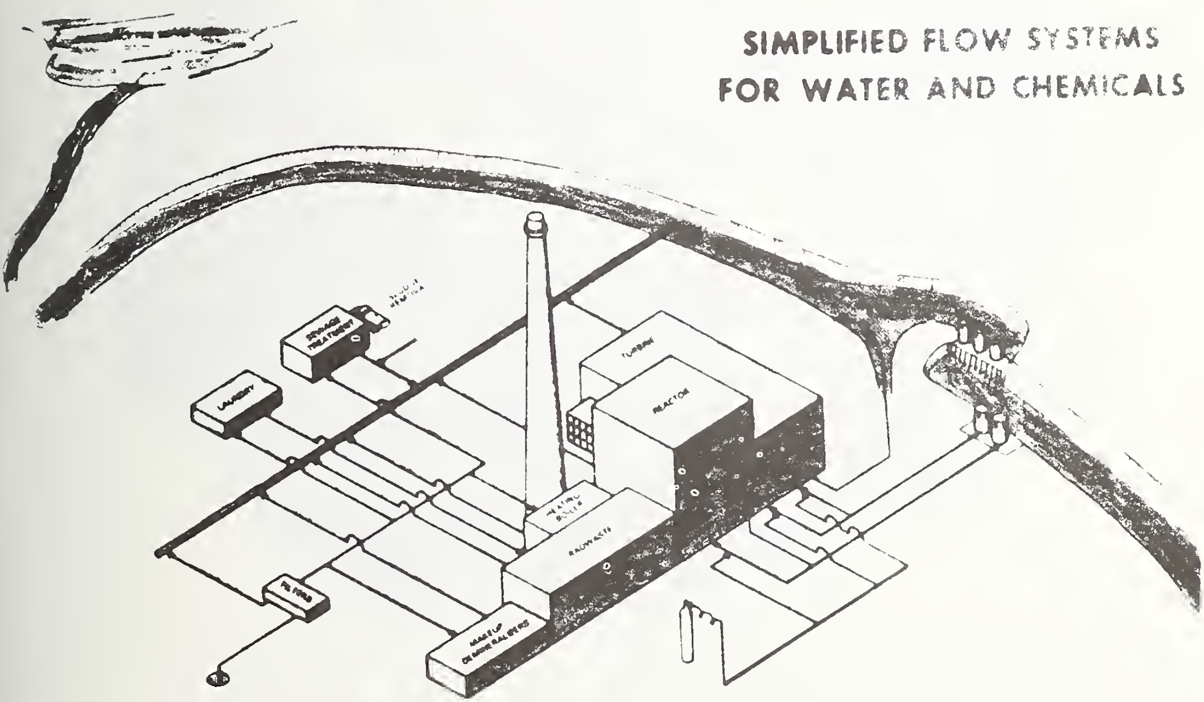

Figure 2.

EXPOSURE PATHWAYS FOR ORGANISMS OTHER THAN MAN

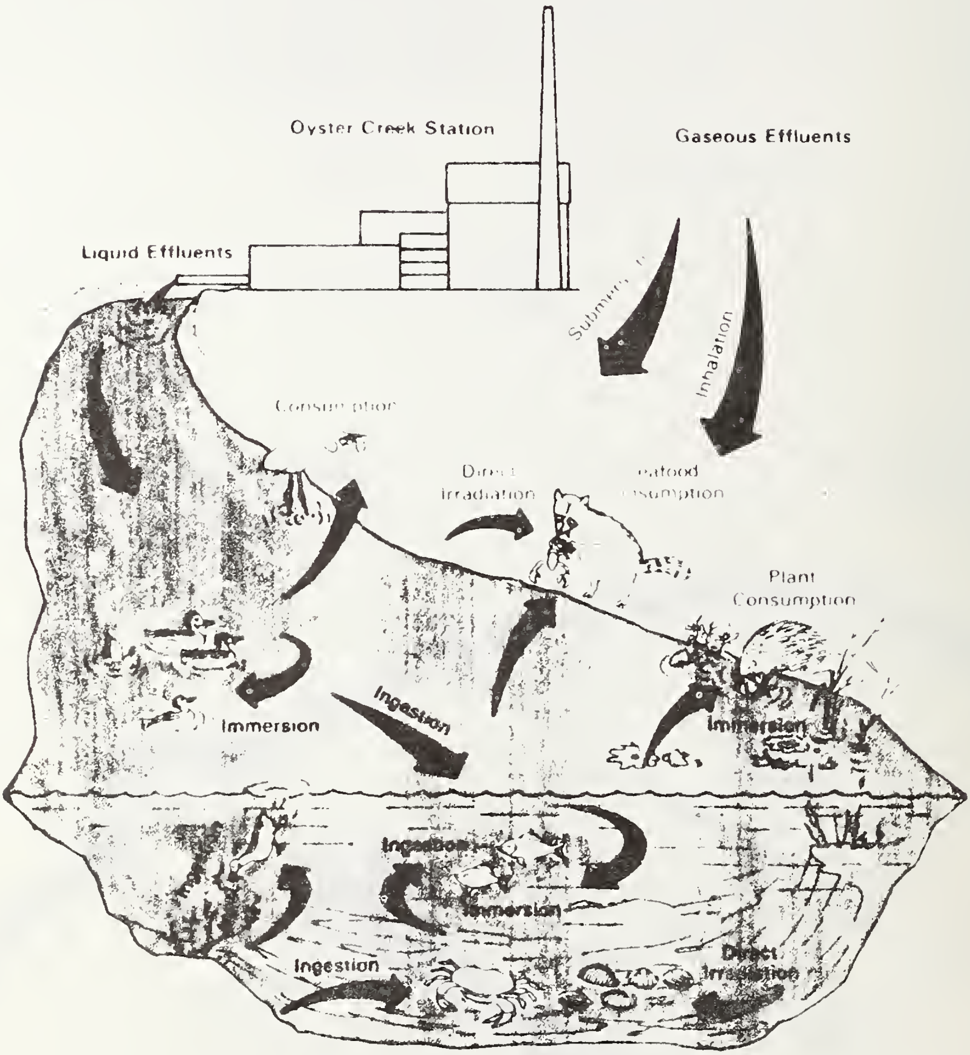

Figure 3.

EXPOSURE PATHWAYS TO MAN

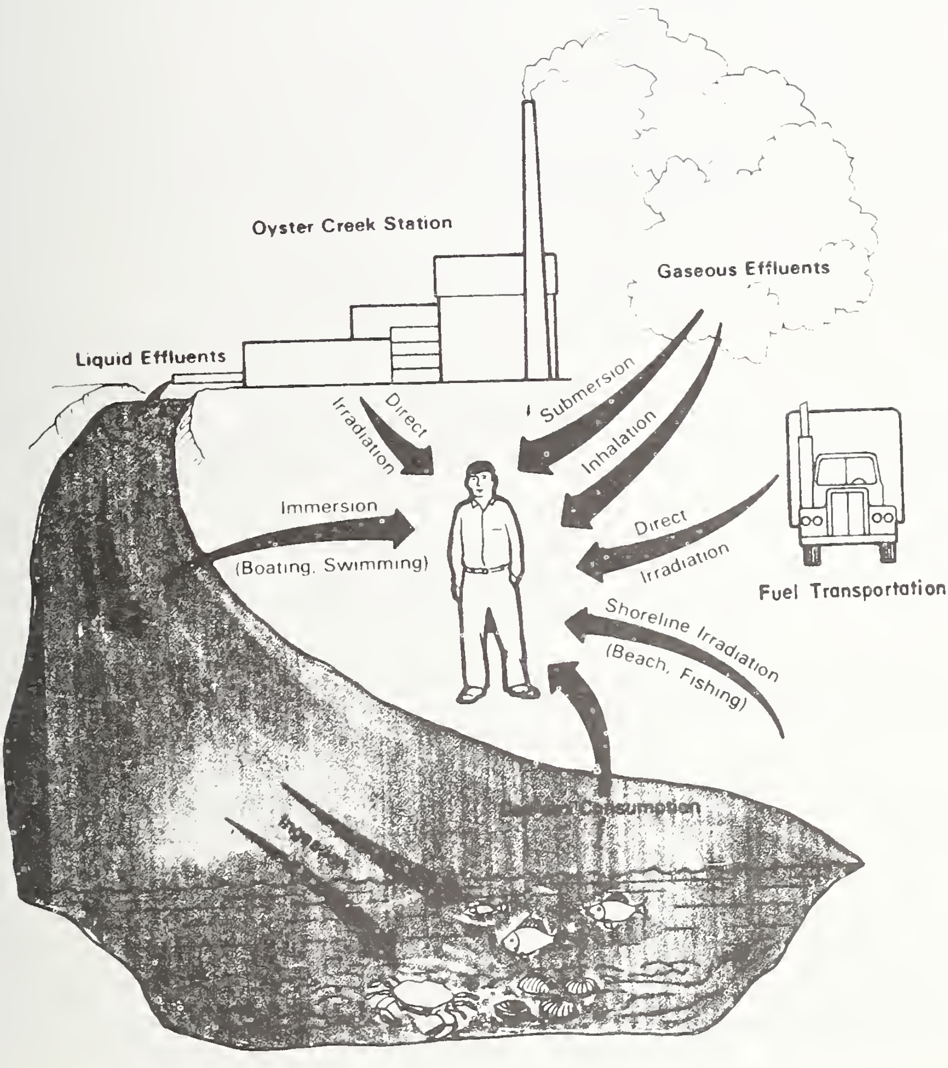

Figure 4.

ECOLOGICAL MONITORING TECHNIQUES

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Today with all eyes and ears focused for the first time on environmental control it becomes more and more important that we as teachers and students work together, armed with a good foundation and knowledge of the field of science so glibly talked about today and yet so little understood. I am of course referring to the study of ecology. Ecology is the realm of those who choose to look into the many facets of both physical and biological science as they would a diamond, and in so doing bask in the interplay that is constantly going on. The interactions of plants, animals, soil, water, light, temperature and inbred instinct or behavior makes for the most complex of studies. The environmental factors which are optimum for one species may be disastrous to another and no single factor acts alone. We can be guilty of both under simplifying the study of ecology or over simplifying it, but the most important thing for us to do is to develop an understanding of the basic concepts of ecology and with this knowledge we can then make some value judgements as to the effect of any large scale disturbance of a delineated ecosystem. Our interest today is in the techniques which we can use to study the terrestrial and aquatic ecosystems on and around areas which will be used for nuclear energy production.

Before any definite construction plans can be made for a power plant of any kind, it is imperative that studies be made to determine the existing ecosystems at and surrounding the proposed site. Years ago, the main conditions studies were the engineering feasibility and the economic restraints. Todays industries must go far beyond yesterday and commit themselves to a quantum jump in the way they examine, interpret, and preserve the existing ecosystems and control the adverse effects which building a nuclear facility is bound to have in an area.

In approximately 2-2 1/2 years between site selection and ground breaking, a fantastic amount of work must be done in order to determine the ecological relationships both in the water from which the reactor draws its coolant and on the land which may be affected by any materials discharged into the air.

In developing an ecological monitoring program for a reactor site, a systematic approach must be taken to insure all necessary parameters are examined. In order to do this, two things must be considered.

First, the site characteristics must be identified, i.e., is this site located on an ocean or estuary, on a fresh water lake or river, is it in the south, east, northwest, etc., or on a reservoir in a southwest desert area. Each has its built in set of characteristics which make it and its flora and fauna unique.

Second, the type of generating and cooling system must be considered since the three or four major cooling systems each have built in operational and construction problems. A once through cooling system must be treated in one way, a closed cooling system with towers or a cooling pond in others. As soon as these are decided upon, it is then necessary to list all of the potential impacts which can occur from the beginning of construction to operation, and indicate where these impacts will occur on the site, or possibly several miles away.

At this point, for each impact it is important to identify the significant pollutants which will be released into the environment such as heat, chemicals, radionuclides, etc., and the changes their release will have on the physical, chemical and biological characteristics of the site. All construction activities such as earth moving, siltation, dredging must be examined to postulate impacts.

Once these impact areas are identified they can be separated into physical and biological parameters and a rationale developed for a monitoring program in each.

Any biological monitoring program must be constructed around the use of indicator species. These must be carefully selected as to their abundance, life cycle, ability to concentrate heavy metals, toxic substances, or isotopes and their sensitivity to changing environmental factors. A clear picture must be established as to their place in the ecosystem. Once the indicator organisms, terrestrial or aquatic, are selected the monitoring plan can be designed. The techniques and equipment can be prescribed that will give the most accurate and reliable data when used in the proper collecting sequence and time schedule. The number of man hours and cost of monitoring is important to know for each monitoring technique. It is just as important to know what not to monitor as it is to know what to monitor. A wrong judgement early in a program can lead to an enormous cost with little valuable information gained.

The first step in an ecological assessment is to look at the entire site area, noting first the edaphic or soil factors such as structure, nutrients, pH, water holding capacity, etc. and second, the climatological factors both of the past and present. In aquatic monitoring, we use the water itself as the base of our ecosystem and must check all of the chemical and physical parameters operating in this media. These abiotic or non-living factors set the stage upon which all life plays.

In order to obtain enough information on the climate, records must be checked back 20-30 years and this long term meteorological data compared with a complete set of data developed over the years before construction. A meterological tower is usually the first monitoring system constructed on the site.

A soil scientist must do a complete analysis of all soil types which exist on the site and should indicate their usefulness to support plant life and form natural wildlife habitats. The soil studies must include drainage patterns, erosion and siltation rates of the soil types and their ability to absorb water. If drainage patterns are going to be changed due to construction, it is important to see how these changes will affect specific ecosystems, i.e., will they fill in existing marshes or swamps, deposit silt on forest floor to the extent it would kill the trees, or cause wash out areas where the soil cannot absorb the excess water as it runs off paved surfaces. All of these can be potential disasters and reactor sites must be designed to prevent this happening.

Aerial photography with good color resolution or infra red can give the first break down of a terrestrial ecosystem to establish or delineate the major plant associations and habitat areas, i.e., marsh, swamp, pine forest, open field and hardwood forest. Ground proof or truth is then obtained by doing quadrat analyses or transects depending upon the type of habitat to be studied. In most cases random sampling of 1/100 acre quadrats are taken in each habitat. The number of quadrats will vary according to the size of the habitat. Every species of plant will be identified in each quadrat, recorded, then a specimen of each species collected, marked and pressed for reference. Generally speaking, 50-100 quadrats will suffice per habitat and the compilation of the number of different species and their frequency will give a good picture of the plant associations existing at present. The general health of the ecosystem can very easily be assessed by studying these plant associations, since these are the producers which provide the food directly or indirectly for all of the animal inhabitants. A study of this intensity will almost always reveal the presence of the major plant species as well as any which are rare or endangered. The field work must begin in early spring and continue through the fall to give a true picture of the flora.

Natural ambient salinity must be established both in the air and soil so that any tests made after the reactor goes into operation will be interpreted against a natural air salt deposition base line. As it is possible, plots of natural and cultivated plants should be established at prescribed distances from the power source to determine growth rates before and after initial start up.

Certain types of plants such as lichens, mosses, ferns and spanish moss tend to concentrate isotopes in their tissues naturally since they absorb most of their nutrients from the air. These must be carefully collected and analyzed for natural radiation levels

and a monitoring program carried out both pre and operational. Radiation meters called thermal luminescent dosimeters placed in the areas where the plants are collected check the ambient radiation and from these data a comparison can be made to see if there is any biomagnification.

Faunal studies must be started at the same time the floral studies are begun and these are first made on a qualitative basis to see the numbers of species in the major consumer levels, i.e., herbivores and carnivores. It is very important at this time to establish food chains and webs and select certain animal species at each trophic or energy level, which will tend to concentrate any radiation or toxic materials as they go through the process of eating or being eaten.

Once the basic studies are made, it is extremely important to go back and begin population studies of indicator species both plants and animals, to determine whether they will be able to move into the surrounding areas where construction begins and become established there or whether they will be completely eliminated from the reactor site and its environs. It is necessary to understand normal population fluctuations as they occur seasonally and yearly in plants and animals and not make snap judgements when the first changes are observed.

Assessments must be made as to the effect of heat released into the atmosphere from cooling towers to see if this will produce enough change in atmospheric moisture or rainfall to affect terrestial habitats.

At the present time infinitely more work has been done on aquatic monitoring techniques since it has been the main practice to use a once through cooling system where water was taken from a river, used for cooling the turbines, condensers, or the reactor itself and returned at a temperature greater than the receiving water. The monitoring techniques used to establish base line aquatic abiotic data are generally those used for hydrological studies such as current patterns and velocity and general physical and chemical parameters.

Once we begin to examine the living organisms in an aquatic monitoring program the work becomes very complex. The first problem is to determine exactly what the resources are that we must be most concerned with because it is virtually impossible to deal with each species. If we are looking at a site in a shellfish area, then the benthic or bottom organisms must be studied in great detail. It is important to collect and identify the species and abundance of algae that serve as their food source and check their primary productivity with an increase in temperature. The bottom itself must be sampled by using an eckman or peterson grab or a biological sled to collect the bottom surface organisms. These can then be sorted by hand or floated out.

The numbers and species of organisms will be a very good indicator of the bottom conditions since deep or toxic sediments will immediately limit the variety of species able to exist there.

The pelagic or moving fauna must be sampled to determine both the productivity of the waters for algae and the small animals and fish that graze on this "grass of the sea". It is important to determine whether or not water is being taken into the power plant from a spawning area, and if it is how much of the total flow is taken in. Only a portion of the water containing eggs and larva must be taken in at any one time to insure the reproductive capacity and survival of the species from those remaining.

It should be quite obvious that I am barely touching the surface of biological monitoring in this short time but there are a few thoughts I would like to leave with you.

The National Environmental Studies Program has set up a task force of 12 people from the Atomic Industrial Forum, Inc. who are working together with scientists from Battelle Memorial Institute, Richland, Washington to develop national standards and techniques for aquatic and terrestrial monitoring at nuclear power plant sites. This kind of far sighted project should, when completed, save utilities from making costly mistakes in setting up

monitoring programs and should assure a standard, complete and continual assessment of the ecosystems.

It is very possible to provide the energy we need while we protect and, in many cases, improve some ecosystems if we plan carefully and follow through with the changes indicated from our studies. A whole new field of technical and professional training will be necessary to carry out these environmental impact studies and it certainly offers an exciting challenge to young people interested in biological sciences today. We are no longer just talking about the environmental problems, but we are doing something about them. In the word "we" I am including scientists, educators and industrialists working together for the good of all.

RADIATION UTILIZATION IN MEDICINE AND BIOLOGY

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The uses of radiations in biology and medicine are myriad, and it is difficult indeed to even begin to do justice to them in the short time available. The term "radiation utilization" in the present context is taken to include the application of radioactive isotopes as tracers or otherwise, as well as the use of "external" radiations such as x-rays, gamma rays, electrons, and other accelerator-produced radiations such as fast neutrons, protons, pions, etc. I shall arbitrarily divide radiation uses into five categories, namely, 1) radioactive isotopes used as tracers in biomedical research; 2) radiation biology; 3) diagnostic x-ray; 4) nuclear medicine, and 5) radiotherapy.

Radioactive Isotopes in Biomedical Research

This subject is enormous indeed. The principles involved are rather obvious. It is possible to substitute for a nonradioactive atom such as iron in a chemical or biochemical compound, a radioactive form of iron. Neither the compound nor the body, so to speak, "knows" that the substituted compound is any different from the normal e.g., it acts (with rare exceptions) exactly as does the normal compound. Thus, if the material is administered to a biological system, it will distribute within that system in a manner identical to that of the normal compound. The only difference, of course, is that one can find precisely, by means of the radiations emitted, where the compound has gone, either in the entire body, organs, cells, or biochemical compounds. This extremely valuable and powerful tool has been used to advantage in virtually every aspect of biomedical science. The amount of information gained has been great indeed. Our knowledge of biochemistry, physiology and medicine has taken several quantum jumps forward since the introduction of the use of radioactive tracers in biology and medicine.

Radiation Biology

The term radiation biology conjures up in the minds of most the study of the effects of radiation in biological systems, and this indeed does constitute a sizable fraction of the work in radiation biology. This is an important area. And while we have learned a great deal about the genetic and somatic effects of radiation, there is still a great deal more to be learned. The approaches developed in studying the effects of radiation have had a profound impact in toxicology in general. It has stimulated a much closer examination of the shapes of dose-effect curves, detailed examination of what might be the effects at low doses and dose rates, and the long term (over many years as opposed to hours or weeks) effects of toxic agents. These concepts are now carried over into the study of a number of potentially harmful agents, including some drugs, and potentially harmful agents released into the environment.

Radiation biology, however, includes much more than just a study of the effects of radiation. It represents the interface among several different disciplines, including physics, chemistry, biology and medicine. It was obvious from the start that, in order to understand the effects of radiation, it was necessary to know more about the biology of the systems involved. Thus, in the course of studying radiation, a great deal of very basic information has been obtained at the biochemical, cellular, organ and whole-animal levels. In fact, whole new areas of endeavor have either had their origin in radiation biology, or have been greatly stimulated in their development by radiation biology.

Often it is forgotten where these areas of endeavor did in fact originate. As examples, consider organ transplants. Definitive and successful work in this area was done in connection with radiation, namely substitution of injected bone marrow as a method of treatment of large-dose whole body radiation exposure, in which the bone marrow and thus the blood cells can be severely and even fatally depressed. After much work it was shown clearly that the transplanted marrow "takes" and grows in the recipient. Bone marrow transplants have been and are used now in human beings. This was followed by transplant of kidneys, which,

although originally involving whole body radiation to depress immune response and thus the possibility of rejection, is now frequently done by means of immune-suppressing drugs. The kinetics of normal cell proliferation, of a number of organs in the body, was studied initially in radiation biology in order to understand the effects of radiation. Radioactive isotopes, particularly tritiated thymidine which goes selectively to DNA in the cell nucleus, has been used world-wide in this connection. There are now organized groups in this field, and a separate journal. Similarly, radiation biology stimulated the detailed study of the kinetics of tumor cell proliferation. The studies have revolutionized our concepts of how tumors grow, and this in turn has changed decidedly our ideas with respect to radiotherapy and other forms of tumor therapy.

The field of immunology, while developing in its own right over the years, received a large impetus from radiation biology. Radiation affects not only the body's capability to respond in terms of antibody production, but also severely depletes the population of lymphocytes which play an important role in immunity. Extensive studies in both of these areas, using radiation, has contributed enormously to our understanding of immune processes. And of course, radiation biology has played a very large role in the continuing effort to transform radiotherapy from an empirical approach to one based on a sound understanding of the time course of events in the tumor and normal tissue as the treatment is applied.

Thus radiation represents a powerful investigative tool. A widespread approach to the study of biological functions is to perturb a system and to observe the effects of the perturbation and the recovery from it. Radiation is a unique, clean agent that can be applied precisely and quantitatively, and thus it has been widely used in this connection.

Diagnostic X-rays

Almost everyone has had x-rays taken for some reason, and is broadly familiar with the process. The approach obviously allows one to obtain information on internal organs that connot be obtained otherwise. It is a very widely used and necessary tool in medicine.

There have been made and are being made a large number of improvements with respect to equipment, types of radiation, and x-ray film, to increase the quality of the image. Also, considerable effort is being made, through use of image intensifiers, reduction of size of field and other approaches to obtain the same amount or more diagnostic information with less radiation dose to the patient. Among the interesting new approaches now being considered is the use of particles such as protons to take radiographic pictures. A highly monoenergetic beam of protons is used. In a homogeneous medium, all such protons will come to a stop at precisely the same depth. However, even small differences in density in the medium traversed, such as those that occur in soft tissue, will "spread out" the beam. Determining where the protons come to rest will reflect even rather small changes in density. This approach allows the possibility of visualizing soft tissue structures, which can be seen only vaguely or not at all in the usual x-ray films. The dose to the patient can be very small.

Nuclear Medicine

Nuclear medicine can be narrowly or broadly defined. In the present context I shall use it to indicate primarily the use of radioactive isotopes in diagnostic and therapeutic procedures. First, with respect to therapy, radioactive isotopes have not lived up to original expectations. In some instances, and the thyroid is a classic example, radioactive iodine can be made to localize to a very large degree in the gland. Thus, a large radiation dose can be delivered to the thyroid with relatively little dose to other organs. This approach allows one to treat certain cases of hyperthyroidism, and some types of thyroid cancer. Other, less attractive uses of injected isotopes in therapy can be cited; however, suffice it to say that the uses of isotopes for these purposes are limited and far fewer than originally contemplated.

The use of radioactive materials in diagnostic procedures, however, represent a completely different story. There are a number of "blind spots" in the body that cannot be evaluated easily or at all by the use of diagnostic x-rays and/or other techniques. Included among these are such organs as the parathyroid, the pancreas and the thyroid. Through the use of radioactive isotopes, it has been possible to obtain information that cannot be obtained in other ways. Initially, nuclear medicine was limited almost entirely to the use of iodine for evaluation of the thyroid. However, the rate of progress has been phenomenal, and nuclear medicine now represents one of the most rapidly growing areas in medicine.

The objectives of nuclear medicine can be characterized as follows:

1) To study and quantify dynamic processes, e.g., heart and lung function.

2) To measure the size of physiological compartments or pool. By tagging procedures one can determine, for example, the plasma volume, the blood volume and the red cell mass.

3) To measure the functional capacity of organs. The rate of uptake of certain isotopes of labeled compounds in organs, such as iodine in the thyroid, provides a quantitative measure of the functional condition of the organ.

4) To delineate morphology. As an example, iodine can be given which localizes in the thyroid. By means of collimation and imaging procedures, a "picture" of the organ can be made which allows one to determine if there are abnormalities in its structure.

As illustrations of what can be done, several figures are provided. Figure 1 is an image of the thyroid made with the isotope techniques using 99^{m} (above) and a new isotope I^{123} below. Technetium-99m, developed at Brookhaven, is very widely used in nuclear medicine. The lower image, obtained with I-123 is better than that obtained with technetium because the characteristics of the rays emitted are more suitable for detection purposes. In Figure 2, are shown images of the kidney and the adrenal, both clearly visualized. The adrenal is visualized with iodine-labeled cholesterol; the kidney with a mercury compound. Figure 3, shows a visualization of the liver, spleen and bone marrow obtained by injecting a technetium-99m labeled sulphur colloid. The distribution is abnormal in this disease; normally there is minimal uptake of radioactivity below the hips. In Figure 4, the easily seen "brighter" spots on the spine indicate the location of metasteses from a cancer of the breast. Visualization was obtained by means of radioactive flourine.

In Figure 5 is illustrated one of the newer approaches in nuclear medicine, fluorescent scanning of the thyroid. In this procedure, no radioactivity is administered to the patient. Rather, the source shown in the Figure, americium-241, is directed at the thyroid, and the 60 keV gamma rays from the source excite fluorescent radiation from iodine. These radiations are collimated and processed in the detector to form the image of the thyroid shown in Figure 6. It is pointed out again that information obtained and represented in Figures 1 through 6 would be difficult if not impossible to obtain by other means.

Another approach being vigorously pursued in nuclear medicine is to utilize new isotopes and compounds to obtain more information, but to reduce the radiation dose to the patient for the same amount of information. As an illustrative example, consider radioactive isotopes of iodine whose half-life is measured in many days, versus a short-lived isotope of iodine whose half-life is measured in hours. Both radioactive isotopes will go to the thyroid, and provide the required information. However, the time required to obtain the information is measured in minutes to at most hours. With the long-lived isotope, however, the patient continues to receive radiation exposure over many days. With the short-lived isotope, the exposure falls to near zero shortly after the required information is obtained, and the radiation exposure is correspondingly reduced. Figure 8 shows a new approach used at Brookhaven, i.e., the incorporation of a very short-lived (20 minutes) isotope, C-11 into the compound dopamine. It is obvious from the figure that the dopamine

does localize in the adrenal. Thus, the organ can be visualized with minimal dose to the patient.

Radiotherapy

Radiotherapy has played and continues to play a central role in the treatment of malignancies, in conjunction with other approaches such as surgery, chemotherapy and perhaps immunotherapy. In a large percentage of tumors, radiotherapy is the approach of choice. Obviously the objective of radiotherapy is to obtain the maximum dose to the tumor, with minimum dose to normal structures that must be irradiated to some degree in the course of therapy. As noted above, radiobiology has contributed enormously to our understanding of tumor cell kinetics and changes that occur in the tumor and normal tissues in the course of treatment.

Newer approaches to radiotherapy involving accelerator-produced beams will be discussed briefly; however, first one fact about some tumors and some radiobiological principals need to be discussed. It is known that, even in very small tumors, areas of reduced oxygen supply exists. Thus, some fraction of the cells are hypoxic, and the presumption is that these cells can continue to proliferate if the oxygen supply is brought back to normal. The radiobiological principles are the following: If cells are rendered severly hypoxic and then irradiated with conventional x-or gamma radiations, the hypoxic cells are protected to a substantial degree, up to as much as a factor of three. This means that it can require as much as three times the dose to kill these cells as compared to normally oxygenated cells. However, with exposure to other more exotic types of radiation, hypoxia protects cells to a much lesser degree. These are so-called "high linear energy transfer", or high LET radiations and include fast neutrons, stripped heavy ions accelerated to very high energies, and negative pi mesons. With high LET radiations the individual packets of energy are laid down in tissue with a much closer spacing than with conventional or low LET radiations, and it is this property that makes radiations not only more effective per unit dose, but apparently insensitive, with respect to their degree of effect, to the oxygen content of the cells exposed.

These properties of tumors and the radiobiological principles allow one to attack two major problems in radiotherapy and both are being actively pursued. Consider Figure 8, in which so-called "depth-dose" curves are given for a number of radiations. Consider first only the two upper curves, for conventional Cobalt-60 radiation and the high LET neutron radiation. Imagine that the tumor is located at the peak of the series of lower curves, at about 10 g/cm^3 (about 10 cm) deep in tissue. With Cobalt-60 radiation hypoxic cells would be protected; with neutrons they would be protected to a much lesser degree. Fast neutrons have now been tried rather extensively by Dr. Mary Catterall at the Hammersmith Hospital in London, and the results to date are quite promising. A great deal of enthusiasm has been generated in the radiotherapy community to use fast neutrons, and a number of machines have been or are being set up for this purpose in the United States and in other countries.*

Now consider a second problem in radiotherapy, as exemplified by the upper curves for Cobalt-60 and neutron radiation. With both, for a given dose to the tumor, one must accept a higher dose to much of the intervening normal tissue. This severely limits the total dose that can be given to the tumor, because of resulting unacceptable damage to normal tissue. The unfavorable ratio can be improved by multiport or rotational techniques; however, the situation is still not optimal.

The series of lower curves (for protons, helium ions, neon ions and negative pi mesons) obviously are much better than Cobalt-60 or neutron in this respect, i.e. for a given dose to the tumor, it is necessary to accept a great deal less radiation in the normal tissue. This in principle should allow one to give a higher dose to the tumor with a corresponding increased probability of control.

A last consideration is pointed out. Among the group of lower curves, those for protons, helium ions and neon ions are essentially "low LET", i.e. like Cobalt-60 radiation,

in the sense that hypoxic cells exposed to these radiations are protected. Thus the advantage of these beams lies only in an improved depth-dose pattern; they have no advantage with respect to high LET characteristics such as a neutron beam has. The exception is pi munus mesons. These particles interact in tissue over most of their length as do protons, helium ions and neon ions. However, at the end of their range, they are captured, principally by nitrogen and oxygen atoms in the tissue. A "nuclear explosion" results with the local production of alpha particles, fast neutrons and heavier recoil nuclear fragments, all of which represent high LET radiations. The net result is that, with negative pi mesons, one obtains markedly improved depth-dose. Also, at the tumor site, one has high LET radiation, and thus the capability of ameliorating the problem associated with hypoxic cells. No facility now exists suitable for the application of pi mesons in radiotherapy. However, facilities are being built at Los Alamos, New Mexico, at Stanford University in California, in England, in Vancouver, Washington, and near Zurich, Switzerland. These beams should become available over the next couple of years.

*Evidence is becoming available indicating that hypoxic cells in tumors may not be the only reason, at least in some human tumors, that high LET radiations appear to be more effective than conventional radiations. This is academic to a degree, however, since fast neutron therapy appears to be superior to treatment with conventional radiations, whatever the reasons may be.

E.B. 53 ♀

$^{99m}TcO_4^-$

^{123}I

10.5%

Figure 1. Image of the thyroid made with isotope techniques using 99^m (above) and a new isotope I^{123} (below).

Fig 2.—Right adrenal scan on patient 2, four days following administration of radiocholesterol. Kidney localization was performed with ^{197}Hg-chlormerodrin setting the pulse height analyzer of the scanner for the ^{197}Hg photon peak. Patient was then rescanned on the same x-ray film without being moved and with the pulse height analyzer reset to the 365 kiloelectron volt photon peak of ^{131}I. Views obtained from the back.

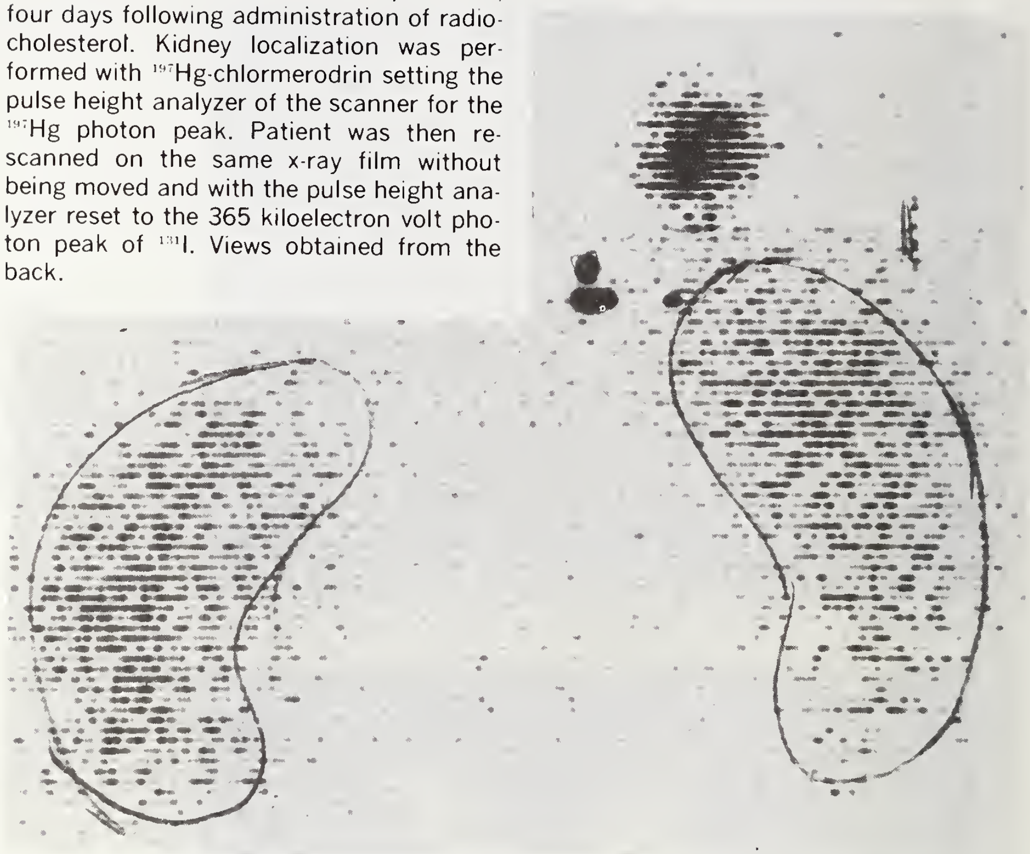

Figure 2. Images of the kidney and the adrenal.

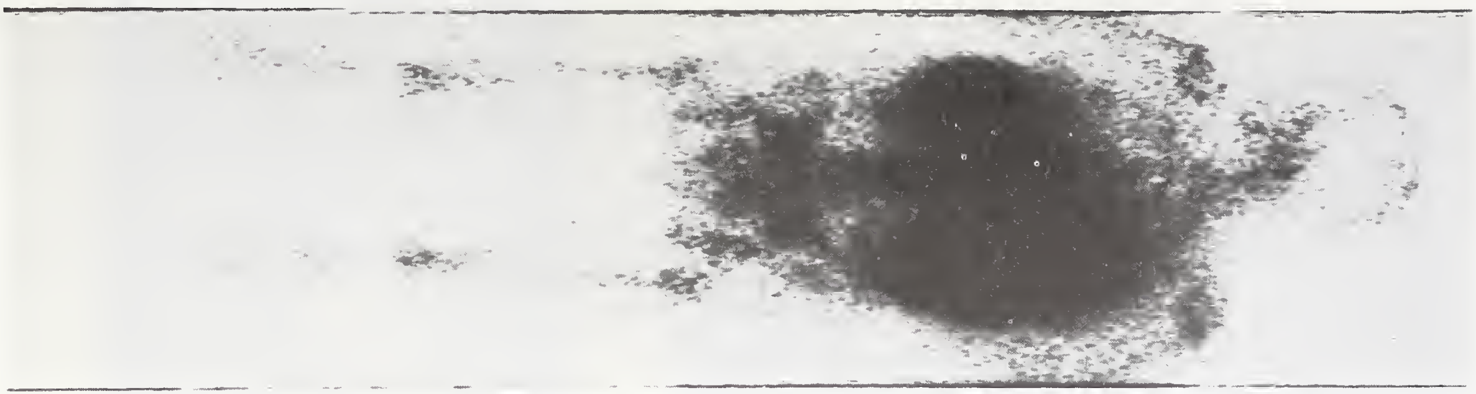

Figure 3. Visualization of the liver, spleen and bone marrow obtained by injecting a technetium-99m labeled sulphur colloid.

Figure 4. Visualization, obtained by means of radioactive flourine, of bone metasteses of the spine from a cancer of the breast.

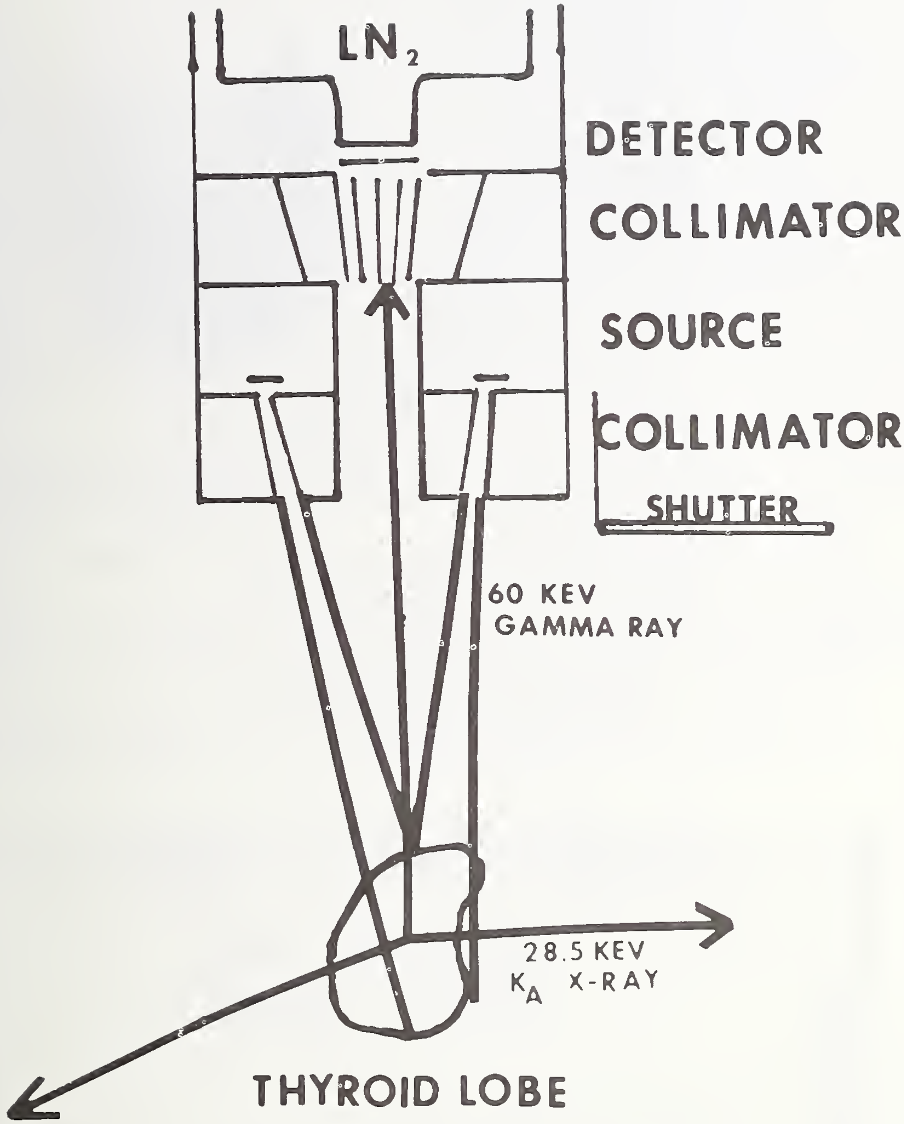

Figure 5. Fluorescent x-ray scanning of the thyroid.

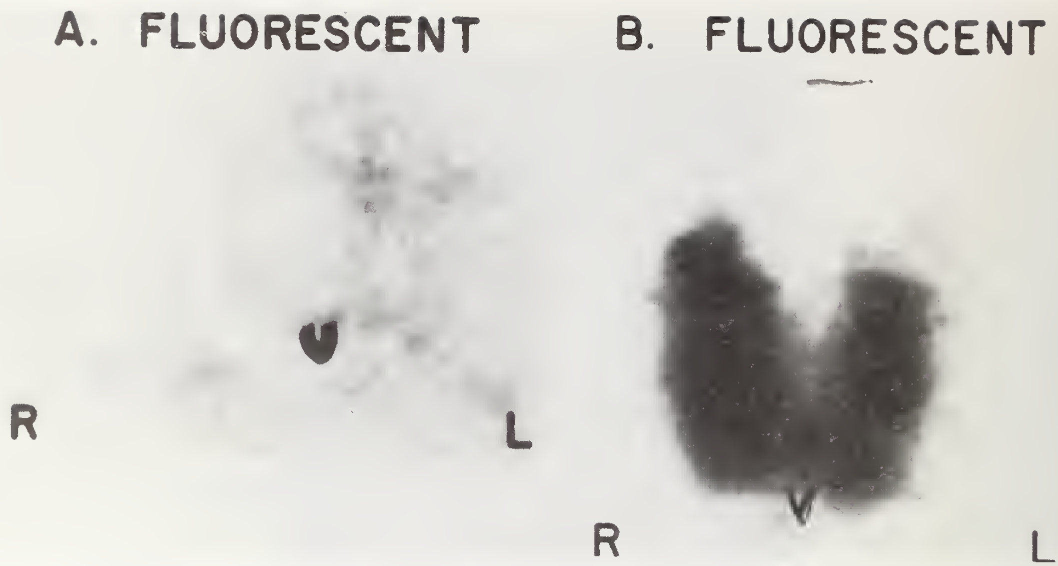

Figure 6. Image of thyroid formed from induced fluorescent x-rays from non-radioactive iodine in the thyroid. The induced x-rays are collimated and processed in the detector.

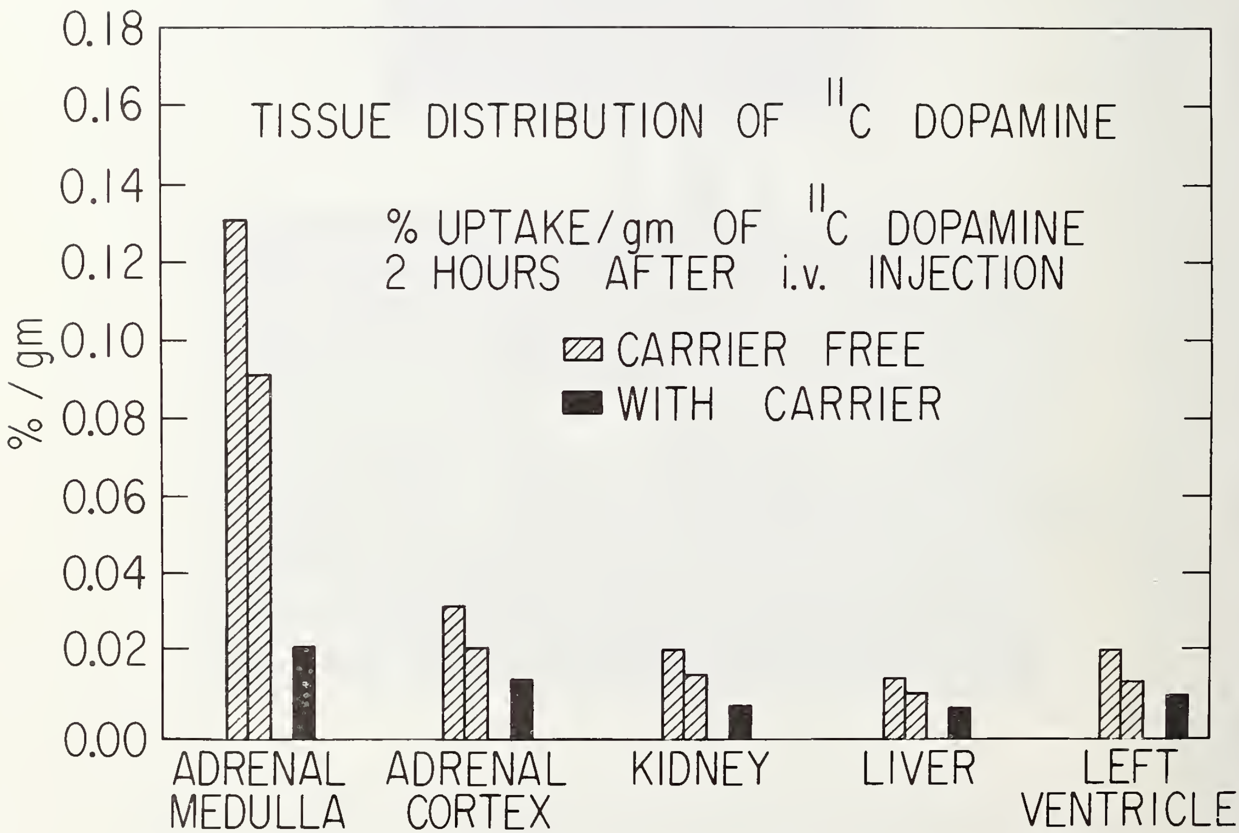

Figure 7. Organ distribution of C-11 incorporated into the compound dopamine.

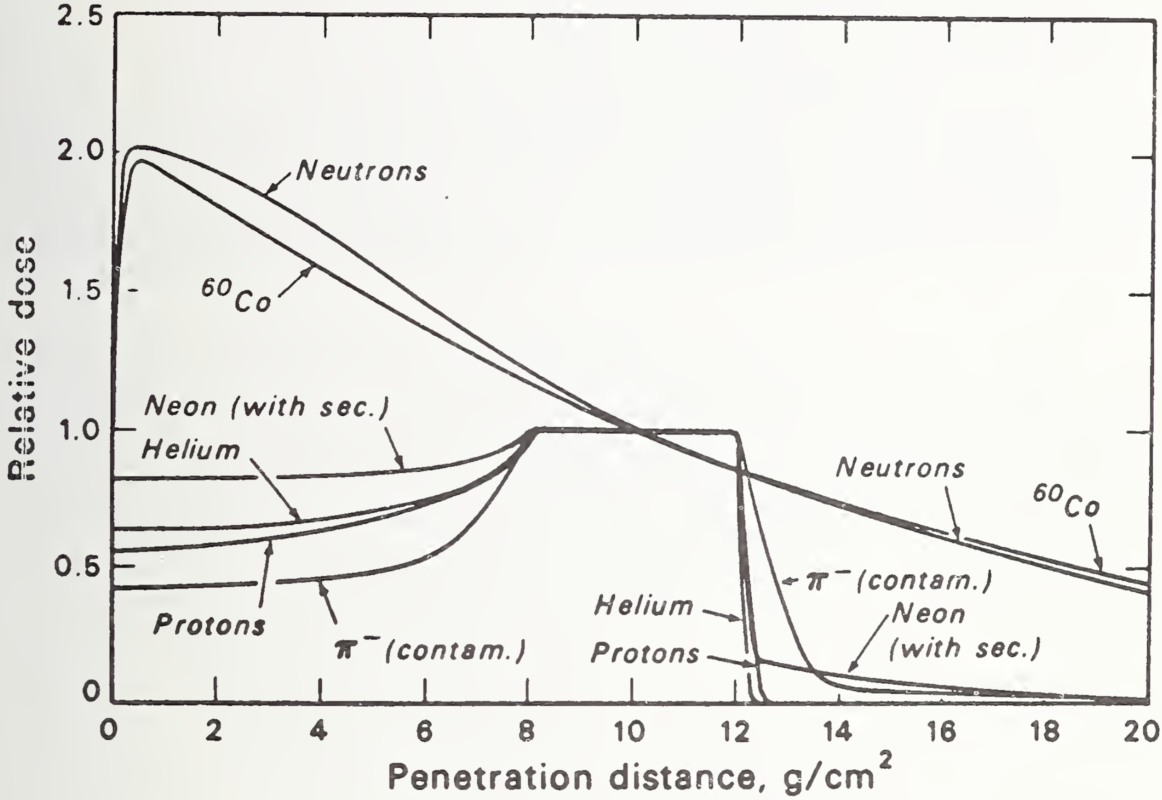

Figure 8. Depth-dose distribution patterns for some conventional and newer radiation beams used for the treatment of cancer.

ADVANCED CONCEPTS IN APPLIED NUCLEAR SCIENCE

G. A. Graves*
(National Science Foundation, Washington, DC)

I would like first to say that it's my pleasure to be here to talk to you participants in nuclear science education today about some concepts which might really be called "advanced nuclear science". I would like to thank both the Washington section of the American Nuclear Society and the Bureau of Standards for this opportunity. I think it's appropriate that both organizations sponsor these activities in nuclear science and that this meeting is held in a place like the NBS auditorium because the NBS has done many things in the service of nuclear science while also serving the broader interests of the nation.

What I intend to do today is to concentrate upon a subject which has been in the news a lot recently. That is the subject of nuclear fusion. The reasons for its publicity will become clear shortly. But I want to disabuse you of any illusions you have about fusion, as well as tell you of its promise and potentiality, right at the beginning. Because whether you say "nuclear fusion", or use other terms commonly applied to this subject such as "controlled thermonuclear reactions" or CTR", or prefer still more vivid descriptions like "bottling the power of the sun", it can be said that you are speaking of one of the most intellectually exciting quests of the human spirit and a quest potentially most rewarding for mankind. For nuclear fusion reactions, if developed and utilized in all their potential forms, offer mankind the promise of nearly limitless energy. At this time of year and in this place, with the shortages of today, that prospect has extra meaning for us.

Fusion reactions offer to produce energy from one of the most common materials in nature - water - and from only a very tiny constituent of that water - deuterium - which is a hydrogen atom that occurs only about once per 6500 ordinary hydrogen atoms in water. Yet this small abundance gives to every gallon of water the energy potential of about 300 gallons of gasoline. That would be energy sufficient to last the world for more than a thousand million years, in contrast to only a few decades of supply offered (even at present rates of consumption) by all the world's oil and only a few centuries at most offered by all its coals and some other less-accessible fossil fuels. Furthermore, a nuclear fusion source might provide energy with greatly reduced environmental consequence and greatly reduced safety concern.

This is not to say that this source is here now, nor to say with any certainty that it can ever be here. It will definitely not be here for a long time. Many of you here in this room may have the opportunity to work on its development as scientific professionals after you have completed high school, college, and graduate work. You may even have worked in this field, if that should be the direction your inclination takes you, for many years before the first economically competitive nuclear fusion reactor is ever built. And if that should be the direction in which your inclinations take you, I hope that you will only be stimulated and not discouraged by this challenge, and that you will find the work exciting and worthwhile.

I would like to outline what I am going to do. I am going to show you a short film[1] first - a very popular film. It has been produced by the National Science Foundation; it outlines some things on fusion that I won't have to repeat. Then I'm going to talk on some of the technical problems of confining plasmas and make some comparisons between energy extraction from fission and fusion. Later I will show you brief glimpses of increasingly complicated and technical aspects of fusion. By the end of the talk I hope you will have some feeling for what fusion may be and have some perspective on its difficulties.

* On loan from the Los Alamos Scientific Laboratory of the University of California, Los Alamos, NM.

I want to touch on something which is sometimes a tender point around the country these days. That is the context in which nuclear fusion so often comes up, where it is treated as "the answer" for mankind "now". That is not the case. I want further to make it clear that the fact that fusion was selected for discussion here is not meant to discredit alternate energy systems or any of the other things the United States is now doing or must do to respond to the problems of the present. Because you people, as well as any other group in the country who are concerned about the matter, are going to have to recognize that the increased use of nuclear fission reactors and the burning of coal for energy production is an inevitability of our time. I do not think that is necessarily undesirable. It is a step that goes toward the utilization of our more abundant resources, in place of using limited, depletable, and actually-diminishing oil and gas as we do at the present. Oil and gas have other much-more-essential uses than the production of heat and should be saved for them.

I think you should realize that neither the present nor the coming energy sources need be unsafe nor environmentally unacceptable. A little consideration will probably show all of you that every resource we wring from the earth and every energy conversion that we accomplish, including nuclear fission, nuclear fusion, geothermal energy, solar energy, etc., invokes some kind of potential environmental concern or degradation, or at least gives some cause for concern. We hear much concern about nuclear fission in this regard. Nuclear fission systems are new. They are the first energy systems that have been thoroughly investigated. They check out very well in environmental and safety regards in the minds of most people and they may look even better when the comparable data for other energy systems are completely in. It is true that nuclear fusion seems likely to be superior to nuclear fission in some respects. But we can not take advantage of any of its impending improvement until we have it, and we will not have it for a long time at best. Meanwhile, nuclear fission systems will go ahead producing power economically and safely, reducing the load on our fossil fuels and helping to conserve them. To illustrate the degree of savings involved, one and one-half tons -- a mere 1 1/2 tons -- of uranium-235 fissioned in a nuclear reactor can produce a million kilowatts of electricity for a year. And that modest fuel consumption relieves us of the necessity of annually mining and burning 3 million tons of coal, or consuming 16 million barrels of oil, to do the same job. In other words, a single nuclear reactor can save us about two days' present coal consumption or about one day's present oil consumption.

Well, what is the source of nuclear energy? We can say that nuclear energy comes from rearrangement of the nuclei of atoms, in response to some stimulating event, into a more stable configuration.

Now all energy release throughout nature generally results from some change leading toward a more stable configuration. You have all seen examples, but you may not have thought of them in these terms. For example, you know that the downward motion of a clock's weight can release energy to operate its pendulum, and that falling water drives a hydroelectric power plant, or that heat may be obtained when you put a chemical into solution or burn something. In all these cases, something gets more stable, and energy is released. Nuclear energy is analagous to these processes, in that it comes from an approach to greater stability, but it is from a different source, the atomic nucleus, and it is of a quite different magnitude.

The physicist likes to express stability of a nucleus in terms of something called its "binding energy per nucleon." (Nucleon is just a general term for the neutrons and protons which comprise the nucleus.) Binding energy is something that can be measured; it tells how strongly nuclear matter is held together. These measurements show that the greatest binding energy per nucleon occurs for nuclei of intermediate atomic weight; that is atomic weights between forty and a hundred. The binding energy is very much less than this for the nuclei of both the heaviest atoms and the lightest atoms. These facts suggest that, under the right kind of stimulus, nuclei of either heavy or light atoms might be induced to turn into the intrinsically-more-stable nuclei of greater binding energy. And if and when these nuclei so change, or transform, there should be energy release. And this does occur.

In the case of the fission of the heavy nucleus, uranium-235, the stimulus for transformation can be the absorption of a neutron even one of negligible energy. When fission occurs, the nucleus splits into two separate nuclei of intermediate mass. In the transformation, a very tiny bit of the total original mass of the uranium nucleus disappears - about a tenth of one percent - and is converted, exactly as Einstein's $E = Mc^2$ equation of mass-energy equivalence would predict, into energy. Most of this liberated energy is manifested as kinetic energy of motion of two new nuclei produced by the fission. And as these nuclei slow down within a very short distance in the medium containing the uranium fuel, they deposit their kinetic energy in the fuel and it appears as heat. A much smaller amount of energy in another form, the "energy of radiation", comes from fission in the form of neutrons and gamma rays; this also eventually is deposited in the reactor as heat. Fission of U-235 is the common process of most of the commercial power reactors of the world, which from features of their construction are usually called "light water reactors" or "LWR's."

Uranium-238 is another and much more common nuclear constituent of naturally occurring uranium; it is one hundred and forty times more abundant than U-235. It too can fission. But unlike the U-235, it requires the absorption or capture of a neutron of significant energy to start its fission process going; the neutrons needed are called "fast" neutrons. The fission of U-238 does not occur very readily in the light water reactors, which have few fast neutrons, so we have to develop a completely new type of reactor in order to take advantage of the very much greater part of the uranium energy that is potentially available to us through the use of U-238. And this is the stimulus behind the development of "fast" reactors" in this country. ("Fast breeders" and "fast reactors" are terms used nearly interchangeably; both require fast neutrons.) Fast reactors are very important to us because they offer to multiply our uranium energy potential by roughly fifty to a hundred-fold. (They would not multiply it by exactly 140-fold because process inefficiencies prohibit fissioning every atom and because LWR's do fission a little bit of U-238.) With fast reactors, uranium already mined by the year 2000 might completely supply the needs of the fission power industry for another century.

Now let us return to fusion. Fusion is similar to fission in one sense, because it also involves nuclear reactions which end up with "particles" that have a stronger binding energy per nucleon than they had in their original form, but in fusion the original constituents mostly join together, rather than dividing. Like fission, this results in energy being released because mass disappears in the process. The energy is carried by the motion (kinetic energy) of the final particles; these particles get stopped in a manner similar to, though not exactly identical to, the stopping of those that come out of the fission reaction. There are some differences between fission and fusion. One would have, for example, for the same energy production, about ten times as many neutrons produced in a fusion reactor as are produced in a fission reactor. There would be a lesser number of original gamma-rays, but as neutrons themselves are capable of producing various gamma-rays, it is a mistake to assume, as many people do, that fusion would be completely free of environmental consequence, or from short-term or long-term radioactivity.

I would like to touch on one or two aspects of fusion and its energy potential by discussing the candidate fusion reactions you have just seen in the film. Figure 1 lists essentially all the conceptual reactions. We will talk only about the top two. They are listed here in the order of increasing difficulty. By difficulty, I mean the temperatures required for initiation of the reaction, for the "stimulus" behind thermonuclear reactions is the collision of nuclear particles through their own thermal motion, which must overcome the electrical charge repulsion which tends to keep them apart. In the left hand column of Figure 1, you see we are dealing with extreme temperatures, from 100 million to two billion degrees. (We'll return later to the role of temperature in making the reaction go.) Both of the first two reactions on this figure are hydrogen isotope reactions. ("Isotopes" are differing nuclei of the same chemical element.) The second reaction, the deuterium, or D-D reaction, is the most abundant potential energy source referred to in the film. We can get deuterium from the sea (or any other body of water). If we could use it in the D-D fusion reaction, we would have an energy potential of 300 gallons of gasoline for every gallon of water (yet nearly 99.99% of the water we started with would

remain unchanged).

The upper reaction of Figure 1, the D-T reaction, has a lower temperature "threshold" - that is, it should be easier to produce - than the D-D reaction and it is the one through which fusion will most likely first be demonstrated. The "T" there stands for tritium - that's a hydrogen nucleus which contains 3 particles, two neutrons and a proton. Tritium does not occur naturally. It is weakly radioactive and has about a twelve year half-life, so it disappears on you whether or not you use it. It would need to be produced as needed, and it could be produced in fusion reactors by neutron reactions with lithium. A neutron comes from the D-T reaction, so it is possible (or it looks possible) to produce a fusion reactor containing lithium in the material surrounding the reaction zone and in which that neutron can be used to regenerate the tritium needed to continue the operation.

Our potential tritium supply, though derivable mainly from lithium, represents through the D-T reaction a very large energy resource, for lithium is fairly abundant. The thing to keep in mind is that nuclear reactions are about a million times more energetic per event than chemical reactions. So one can afford to expend unconventional amounts of energy to obtain nuclear fuels. He may utilize ores, rocks or seawater having just one part in thousands or one part in tens-of-thousands of the material desired. Even though the rest, which is the bulk of material, might be waste, the economics of ore utilization can be favorable because the eventual energy return from nuclear reactions is so great. The ordinary nuclear fuel uranium (if used in fission breeder reactors) or the nuclear fuel tritium (if derived from lithium and usable in fusion reactors) would provide an energy resource greatly exceeding that of all the fossil fuels of the world. The gain over fossil supplies would be at least a hundredfold in either case. The potential gain from the availability of D-D reactions would be very much greater still.

The problem with making a fusion reaction go is the fact that one has to bring the two reacting nuclei very close together before it can occur, and pushing nuclei together is difficult. This could be done in an accelerator, but it is not efficient and one could not get much energy yield from the small currents. One way being considered is to heat the material and then to rely on its thermal motion to cause enough collisions per unit time to sustain the reaction. The nuclei of the hot material tend to randomly strike one another from time to time. But their mutual charge repulsion (the Coulomb forces) would require that the material be "heated" very much - i.e., that the nuclei have very great energy of motion - before they are able to undergo those reacting collisions with any frequency. The degree of heating required for these reactions to work was expressed in millions of degrees of temperature at the left of Figure 1. Since no solid medium can survive those temperatures, we have been led to consider the two general approaches to nuclear fusion (and four pathways) shown in Figure 2. These approaches do not require a material to contain the reaction. (There is at least a third non-material confinement method, which works in nature - the gravity of the sun holds a fusion system together, but we can't use that here on earth.

Various fusion machine concepts seek to employ magnetic fields to hold the reacting material away from walls. There are three approaches, all coming under the general name of Magnetic Confinement: they are the tokamak, the theta pinch, and the mirror machine. An alternate concept is to produce a reaction which is so brief that it has occurred and its effects have been dissipated before any deleterious contact with the walls has been made. This is sometimes called "Inertial Confinement". It is the idea behind the concept labelled "laser-pellet fusion," also known as "laser-induced fusion." The focus of today's presentation will be on magnetic fusion, but I may later give a quick summary of the status of laser pellet fusion.

Magnetic Confinement Fusion seeks to restrain energetic (hot) particles by magnetic fields, as said before. The purpose is both to confine and contain the reaction and to prevent reacting particle loss. Any loss of particles is bad. It lowers reaction efficiency, it cuts down on operating temperatures, and it produces other problems in handling the particles that get away, especially since these are capable of generating contamination which might quench the reaction.

Magnetic confinement is possible because, at the high temperatures involved, all material undergoes a complete dissociation into free charges (electrons and ions) to form a "plasma", and charged particles don't cross magnetic field lines. But there are also problems, because magnetic fields don't restrain particles which travel along field lines. Leakage is always possible in any system that involves discrete magnets, because there are always some field lines which leave the system and provide potential leakage paths. So an element of all magnetic approaches, indeed a hallmark of magnetic fusion work, is the construction of very complicated magnet assemblies to try to twist and turn the magnetic fields in such a way that they offer no ready path for a charged particle to escape.

A second problem confounding any simple approach to preventing loss is that the collective behaviour of charged particles in a magnetic field is not like that of "isolated" charged particles. It might be so if there were only a hundred or even a hundred thousand particles, but in cases like we are talking of here, with 10^{12} or 10^{14} particles per cubic centimeter, the plasma material takes on a new character all its own. It does not act like single particles at all. Rather it acts a little bit like a fluid under pressure within a system with soft deformable walls - i.e., acts somewhat like water in a hose made of soft weak rubber, where the water resembles a plasma and the rubber resembles the confining ability of a magnetic field. Any incipient bulge in the wall (field) may grow until there is a rupture and a fluid (plasma) loss. Thus, collective behaviour of plasma tends to introduce new kinds of instabilities and losses - there are pressure reactions against the magnetic field back and forth - and the problems of confining plasma and sustaining an equilibrium reaction within it are very, very difficult.

Experimental research configurations illustrating attempts at stable confinement are seen in the ST Tokamak (Fig 3) at Princeton and in the theta-pinch experiment (Fig 4) known as the Scyllac at the Los Alamos Scientific Laboratory. These have similarities but they are two different approaches. One of them has a very high magnetic field - the Scyllac, for example, will produce an intense magnetic field by discharging a four story bank of condensers into what is essentially a small single-turn-coil located near the man in the figure. The magnetic field created by that single turn discharge will squeeze and compress the plasma or gas, shocking it, ionizing it, heating it, and then doing work upon it; but the hot plasma is only confined for a very short time, at present a few millionths of a second. In the tokomak, stability is helped by the induction of a very high current discharge through the plasma around the ring, but magnetic fields and plasma densities are very much lower than in Scyllac, while confinement times, though still short, are about 100 times longer.

To oversimplify the central problem of fusion, we may state that it is to get a plasma hot and confine it while it reacts; we must invest energy in doing that, but we hope to get energy return from the reactions produced. Quantitative ways of expressing the confinement criteria needed for energy "breakeven" (energy out = energy in) are shown in Figure 5. The product of particle density and time of confinement is the thing that is important; on sound theoretical grounds, that product must be something like 10^{14} (particles per cubic centimeter times seconds of confinement) before one can hope to get more energy out than is used in establishing the reacting conditions. Figure 5 shows that present technology is about two orders of magnitude - that is, a factor of 100 - below achieving this critical value for "breakeven" which is sometimes called "satisfying the Lawson Criterion." There are two regimes in the figure. For the DT reaction, the breakeven prospects are seen to be slightly simpler than they are for the DD reaction, which corresponds to the difference in temperature requirements discussed earlier. (Temperatures enter through the Figure's technical term "Kiloelectron volts"; multiply that by 11,000,000 to get the associated reaction temperatures in degrees Kelvin.) Experimental devices have achieved all values of the three parameters (confinement time, particle density, and temperature) appropriate to breakeven individually, but in combinations of no more than two at a time. In some cases, we've gotten plasma hot enough (like the 100 million degrees that was achieved in the Livermore "Baseball" mirror machine experiment), we have been able to confine plasma in some cases for times long enough to be of interest, and we have sometimes generated sufficient particle densities but we haven't been able to do those three things simultaneously.

Though the net effect is to be about a factor-of-100 away from breakeven, and still requires a lot of improvement, we have made great gains from earlier times. The two most promising approaches - the two machines that come closest to this overall goal - are quite different. One is the tokamak class of machine, which is a Russian concept now being widely studied in this country and, in the thinking of some, the most promising fusion approach. The other, providing a higher pressure, higher magnetic field arrangement, is the Scyllac machine discussed earlier. There is evidence that both machines offer a scaleup in performance for a scaleup in size. Mirror machines offer interesting research possibilities but, because of particle loss, may offer less prospect for development into commercial reactors.

In a fusion system, there are many many attendant complexities beyond attaining confinement. We have to find ways, for example, to be able to inject the material which constitutes the plasma we're going to burn. We also have to develop ways to extract its spent products. We need a means of heating to initiate the reaction. Each one of these tasks requires a technology of its own. We will probably use cryogenic (very low temperature) super-conducting magnetic field coils to provide the needed magnetic field strength; development in this area is still required. There will be questions of removing the heat, regenerating the needed tritium, etc. These last tasks will be accomplished outside the plasma through a surrounding structure (Figure 6) nicknamed "the blanket." There are also problems of nuclear radiation damage, as well as many other complex technical and engineering problems.

How does one get the (heat) energy out? A quick look at Figure 7 shows the amounts and two sources of energy in the DT reaction. Helium carries some of the energy, which can be deposited in the plasma and prove useful in keeping the reaction going. Neutrons carry the rest (about 14 MeV out of an original 17.6 MeV), most of which leaves the plasma and must be collected in the blanket. There is a possibility of adding some further system energy through additional neutron reactions out in the blanket. Neutrons move freely through magnetic fields, and can readily leave the magnetically-confined hot plasma region to experience scattering and deposition of their energy in the blanket, as well as generating (breeding) more tritium there. Surrounding the blanket there must be a large shield to protect the magnet coils from nuclear radiation and its heating effects, and there must also be a provision to pump coolant through the system and utilize the heat acquired to produce power. The basic system requirements of fusion powerplants are shown in Figure 8. Such powerplants would have rather conventional heat exchangers, similar to those in wide use today. That is, heat from the device would make steam, which would drive a turbine, which would spin a generator to make electricity.

Figure 9 shows that the D-D fusion reaction yields energy-carrying neutrons and atoms similar to the energy-carriers from the D-T reaction. The principles of energy extraction from these two fusion systems would therefore be similar, but there are enough significant differences in the amount and distribution of energy that each fuel cycle will likely require its own reactor design to take its pecularities specifically into account.

How would proposed systems look under more serious attempts at powerplant engineering? There are a great variety of answers; Figure 10 shows a portion of one concept. It is a tentative arrangement of a segment of a (United Kingdom) tokamak reactor concept. An interior configuration of a part of the reactor torus (ring) near the plasma region is shown. Such designs must cope with problems of pumping coolant in magnetic fields, providing protection to the magnetic field coils, supporting the structure, withstanding large atmospheric and magnetic pressures, and rendering all elements of the system accessible as necessary to replace them. Keep that in mind as you look at Figure 11, which symbolizes the full torus whose existence as a complete, operating and fully-engineered ring is necessary to provide a fusion energy source for the power system. Lastly, Figure 12 gives one (Princeton Plasma Physics Laboratory) impression of what a combined tokamak reactor and powerplant might look like. The reactor alone, within the shield at the left, would be approximately the width of a football field and would be coupled as shown with very large steam turbines and power producing equipment of the sort described earlier. Other magnetic confinement powerplant engineering concepts, while quite different in detail,

would be similarly complex.

Though success is not automatically assured, in the opinion of many experts it is possible to project the high livelihood of success for an experimental demonstration of "scientific feasibility", perhaps around 1982 if everything goes well. That is, we may by then get as much energy out of some one of these machines as we put into it, for a single operational pulse. Ultimately one will want to produce this energy in a rapidly repetitive way and to get more energy out than he puts in. That development will require a series of large and expensive "plasma test reactors", "experimental power reactors", etc. Consequently prototype power reactors providing some significant electrical output probably will not likely be available any earlier than 1990 and possible only by the year 2000. But at some time near then, if we are lucky, we may have a large-sized fusion power system which works and, following that, it would seem likely we would have many more.

Let's now speak about the other general fusion approach which is being pursued: this is "laser-induced" fusion. That area also has complicated implications and I'll only briefly discuss them. I mentioned that it isn't always necessary to work with a magnetic field. That idea occurred to people who designed and studied lasers some time back. Let us imagine that you can take a very tiny pellet containing fusion fuel material - we typically think of something smaller than the head of a pin - and selectively heat the pellet material on its outer surface by use of an intense pulse of laser light (Figure 13). If a layer of heated material is abruptly vaporized, violently expanded and driven rapidly away from the pellet, enormous reaction forces should suddenly squeeze the pellet and also give the pellet a very hot core. Then, in that extremely hot, but exceedingly tiny, highly compressed pellet (compressed by a factor-of-a-thousand or more from its initial state, compressed in fact, by a factor-of-a-thousand beyond the normal density of a solid) one might expect a fusion reaction to occur. This would take place very, very rapidly and would liberate energy in the form of neutrons and hot plasma particles, even as it blew the pellet apart. But if that pellet explosion were made to take place in a well-designed and sufficiently large cavity, the shock energy on the wall - which might be equivalent to just a few pounds of explosives - might easily be confined with present containment technology so that the energy which was produced could be extracted. A conceptual arrangement for doing this is indicated in Figure 14.

This kind of fusion process requires us to produce temperatures essentially as high as those needed for magnetic confinement. To attain this, the pellet material would need to be compressed to densities anywhere from 100 to 10,000 times that of a solid. That would require laser energies and powers at least 10 to 100 times greater than those of presently existing lasers, so much equipment development is needed and is being pursued.

Now what has been done so far? There have been temperatures attained which were perhaps a tenth of those ultimately required. There is good evidence that interesting compressions have taken place in some experiments. There have been some neutron yields, but they may not signify true thermonuclear yields in the sense described above, where surface-driven-compression initiates internal reactions to create the principal plasma heating. Rather, they may have resulted from a simpler, more uniform heating throughout the pellet's volume. If so, their ultimate energy output will be limited and the further laser refinements now already sought in some laboratories, may be required before system performance advances. These questions as to our true status are yet to be resolved.

There is an analogue for the "Lawson criterion" for laser fusion, which says that one need provide a certain relationship between the density obtained in compression and the radial size of the compressed pellet; that product must also be near 10^{14} (for density in g/cm^3 and radius in cm.) The energetics are such that this should be attained more easily if one starts with a small pellet and goes to a very high compression than vice versa.

How would one achieve laser fusion in the plant engineering sense? Since lasers of the high powers required don't really exist, and for other reasons, it is likely that one must irradiate the pellet by many lasers and from many directions simultaneously to provide

the necessary energy. But the laser pulses involved occupy only a fraction of an inch in space, they move at the speed of light, and they have to arrive at the pellet with true simultaneity from all directions. Severe problems of phasing and control will likely require that all these laser pulses start from one original laser source, whose light output will have to be split, controlled, and amplified in intensity in numerous beams, somewhat in the manner suggested by Figure 15.

For a reactor system, the power generation cavity must have a means of non-destructively absorbing energy from a continuing series of energy pulses or small "blasts", as well as a means of converting the absorbed energy to heat. One proposal (Figure 16) is to use a "wetted-wall" cavity for this, in which some interior liquid surface could be vaporized and blown away by each pulse but immediately replenished. (But most of the heat would take place in liquid behind the wall.) The system would have to be refined to permit the relatively rapid injection of pellets (several per second) on a continuing basis, and assure that these would be unerringly struck by new laser pulses.

Clearly laser fusion systems, like magnetic confinement systems, would have to be complex. But this is true for nearly all energy-producing technologies, and both government laboratories and industry are pursuing this technology to gain a better understanding of its possibilities. The list of some of fusion's potential advantages provided by Figure 17 reminds us of why this is done. In reading this, it should be kept in mind, that fusion is not here yet, nor would it be free of environmental implications. Its difficulty, cost, and (at best) long time to payoff would make it unwise for the government to put all its energy research and development dollars into this area alone. However, it is intended to pursue it as rapidly as we prudently can while taking account of our other needs.

This whole presentation has given you only a quick look at the subject of fusion power. I hope it will not give you the impression that we are never going to succeed, for we are centainly going to try. But I hope you'll also realize that there is a long way to go. We must not say "fusion is coming, so we can forget about those nuclear fission reactors and that smoky coal." We are going to need all our current energy sources, and for a long time. Though we are diligently pursuing alternatives, like solar, fusion, and geo-thermal energy, the fact remains that only nuclear fission power and coal offer to provide any substantial relief over the next 10-15 years from the scarcity of gas and oil.

I. Summary of Film "To Bottle the Sun"

This film relates world energy use to impending shortages and to the future needs of undeveloped societies. It points out the abundant energy in the process which powers the sun, which is the thermonuclear fusion of hydrogen nuclei, and offers an introductory description of the search underway for a method to permit utilization of sun-like fusion reactions here on earth.

Solid materials can not cope with the hundred million degree temperatures required. One approach is to seek a non-material "magnetic bottle" shaped in such a way as to confine the mixture of electrons and ions, a "plasma", into which the reacting material would dissociate at the temperatures involved. Toroidal, or doughnut-like, shapes are among the more promising "bottles" in this regard. Alternate methods, including laser fusion and direct energy conversion schemes are mentioned. The film points out that this research is an early phase of a difficult scientific endeavor in which effort is internationally shared.

This five minute 16 mm film was produced by the National Science Foundation (in coop-

eration with the USAEC and Princeton University) as part of its Search: Encounters with Science series. It is available on a rental or sale basis through Doubleday-Multimedia, 1371 Reynolds Avenue, Santa Ana, California 92705.

FUSION REACTIONS

TEMPERATURE REQUIRED	FUSION REACTION	ENERGY RELEASED
~100,000,000° (10 keV)	$D + T \rightarrow He^4 + n$	17.6 MeV
~500,000,000° (50 keV)	$D + D \rightarrow He^3 + n$ $D + D \rightarrow T + p$	3.3 MeV 4.0 MeV
~1,000,000,000° (100 keV)	$D + He^3 \rightarrow He^4 + p$	18.3 MeV
~2,000,000,000° (200 keV)	$p + Li^6 \rightarrow He^3 + He^4$	4.0 MeV

Figure 1. The Candidate Fusion Reactions

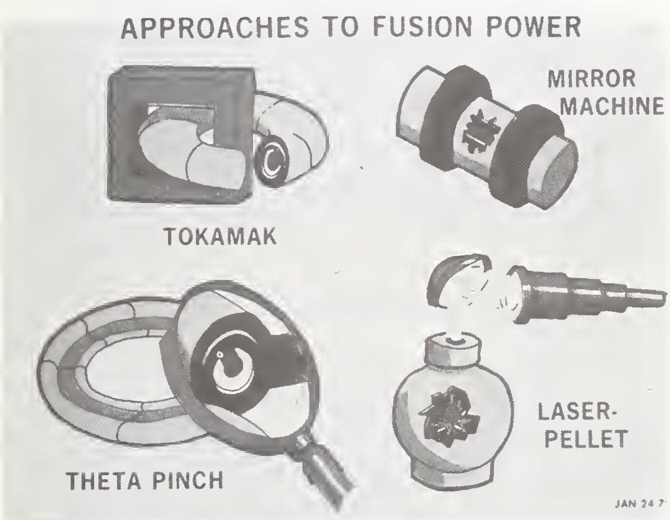

Figure 2. Approaches to Fusion Power

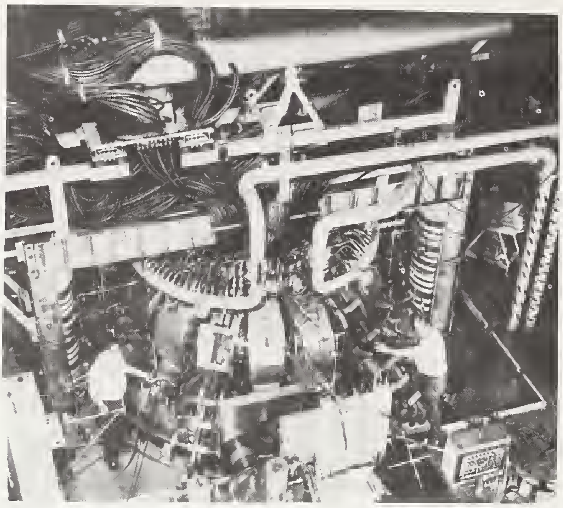

Figure 3. Early Princeton Research Tokamak.

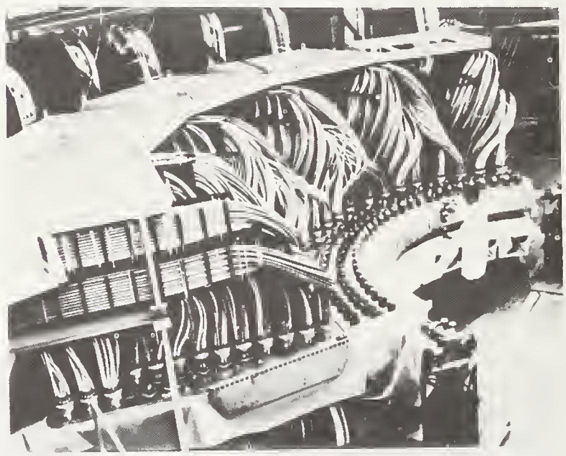

Figure 4. Toroidal Sector of LASL Research Scyllac

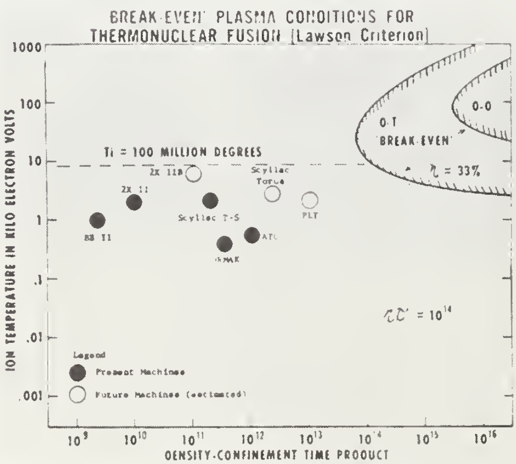

Figure 5. Plasma Conditions for Fusion "Breakeven"

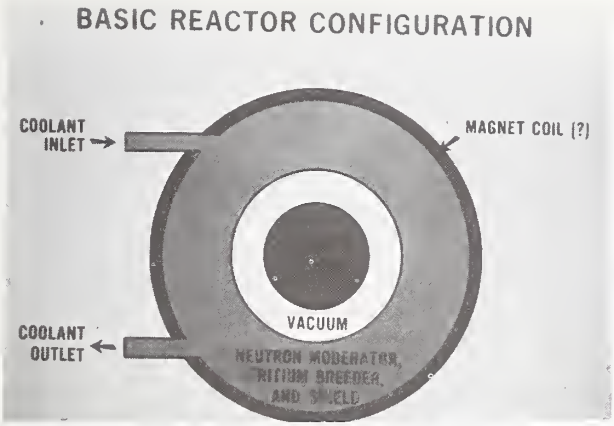

Figure 6. Simplified Reactor Energy Extraction Concept

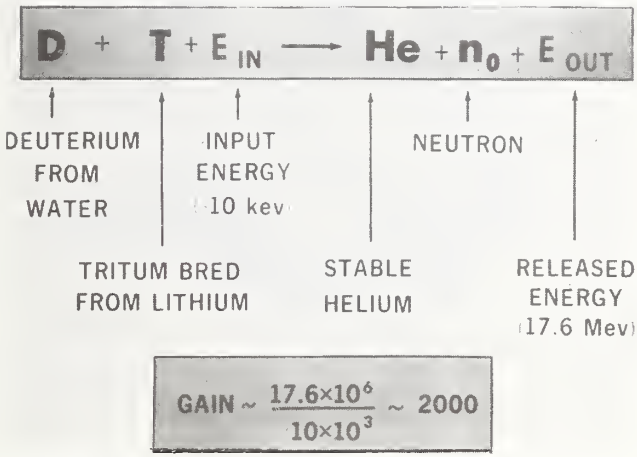

Figure 7. The D-T Fusion Fuel Reaction

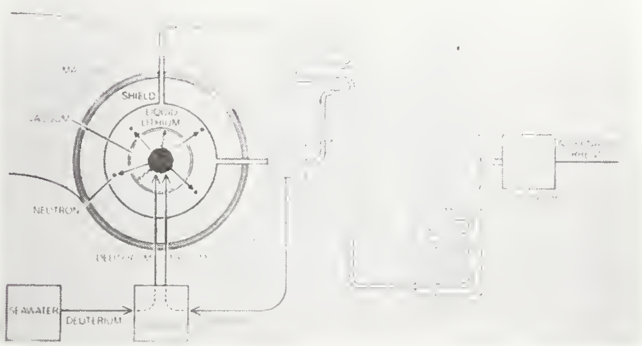

Figure 8. The Basic System Components of Fusion Powerplants

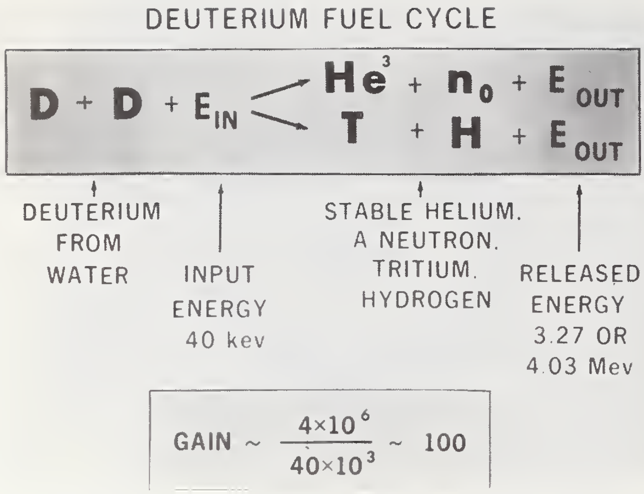

Figure 9. The D-D Fusion Fuel Reactions

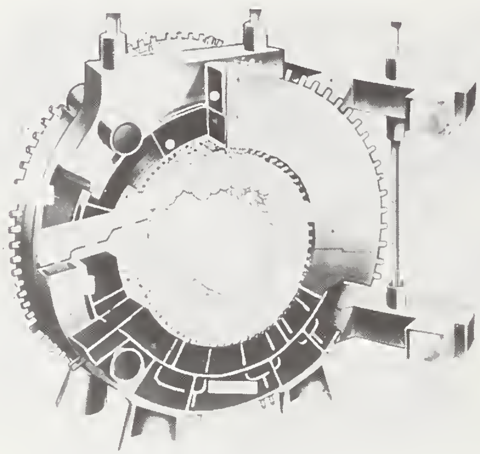

Figure 10. Segment of a Tokamak Reactor Blanket

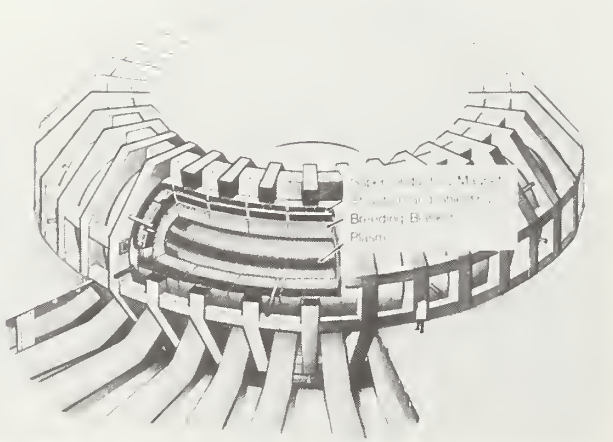

Figure 11. A Tokamak Reactor Torus

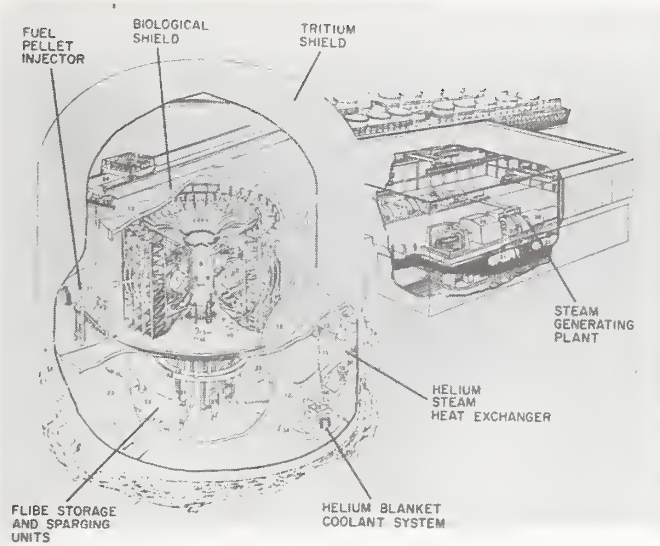

Figure 12. A Tokamak Reactor Powerplant Concept

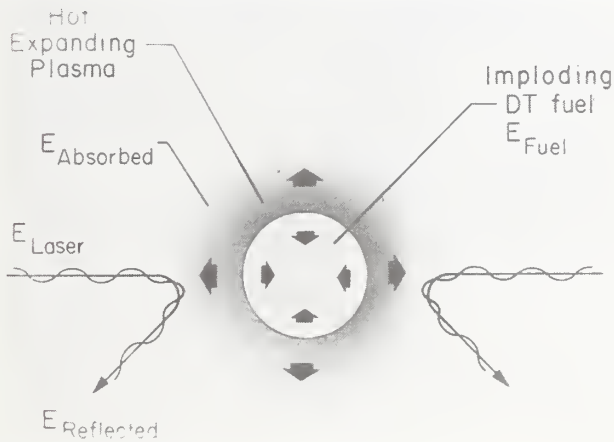

Figure 13. The Basic Laser Fusion Interactions

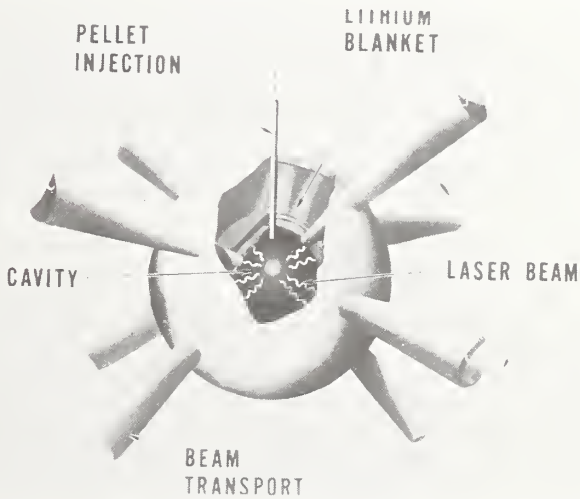

Figure 14. Conceptual Laser Fusion Interaction Chambers

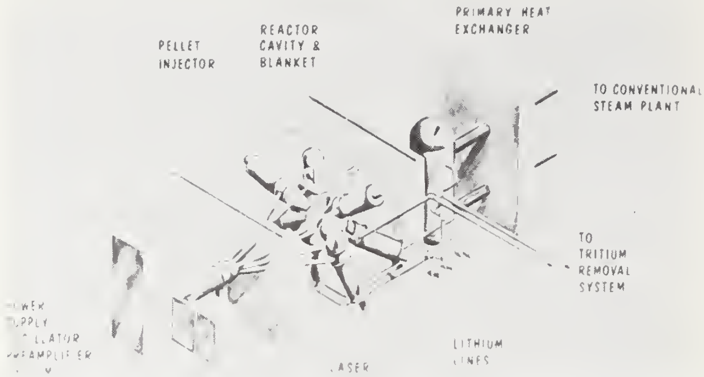

Figure 15. Symbolic Laser Fusion Reactor Concept

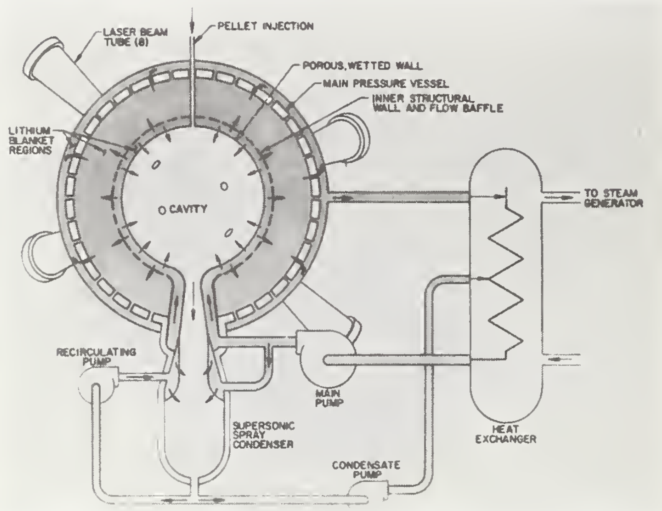

Figure 16. "Wetted Wall" Cavity Reactor System

ADVANTAGES OF FUSION POWER:

1. FUEL SUPPLY PLENTIFUL, COST LOW
2. NO COMBUSTION PRODUCTS, VERY LITTLE RADIOACTIVE WASTE
3. LOW RADIOACTIVITY, REDUCED ASSOCIATED DANGERS
4. NO CHANCE OF RUNAWAY
5. NO DIVERSION OF WEAPONS - GRADE MATERIALS
6. HIGH EFFICIENCIES, POSSIBILITY OF DIRECT CONVERSION

Figure 17. Some Potential Advantages of Fusion Power

PROJECTED NATIONAL AND REGIONAL MANPOWER NEEDS

FOR ENVIRONMENTAL AND NUCLEAR SCIENTISTS

R. L. Murray
(North Carolina State University, Raleigh, N.C.)

The speakers who preceded me have provided a great deal of background information on our needs for energy production with environmental protection and have indicated some of the research that has to be done.

When we talk about careers and manpower needs in nuclear science and environmental science, it is important to make some clear distinctions between different types of work and the amount of scientific background required.

I believe the best way to approach this matter is to describe several typical jobs that we are sure will need to be filled in the future. For each I'll try to answer these questions:

"How much training in science is required?"
"What other skills or knowledge are important?"
"What is the nature of the work?"
"Who employs people for this type of work?"

Dr. Duffy will answer the important question later, "Where can one get the necessary education?"

I am going to take a somewhat broader viewpoint and include jobs in which people function as technicians, technologists, engineers, and scientists. I do so because it provides a larger perspective of the career opportunities for graduating high school students with a good science background.

Health Physics Technician

There is a growing need for workers with skills in the area of radiation protection. As you know, the operation of nuclear reactors is accompanied by the production of high energy radiation - especially neutrons and gamma rays. The fission process also yields isotopes that emit penetrating radiation by radioactive decay. Very strict rules govern the allowed exposure of plant personnel and the amount of radioactive materials that are present in the air or water discharged from a power reactor plant. Measurements of radiation by special detectors must be made frequently at many places in and near the plant. Health physics technicians check the electronic instruments, make surveys or periodic measurements, and analyze and report the important data that assures protection of the public. Graduates of high schools who take a year or so of additional training in electronics are excellent candidates for additional on-the-job training that will qualify them for the position of health physics technician. There are relatively few technical institutes yet that specialize in training people in this area, but the increase in demand for health physics technicians is very likely to encourage more schools to develop programs.

Reactor Operator

High school or technical institute graduates with an inclination toward science and mathematics, and who have interest in the behavior of mechanical and electrical equipment are excellent candidates for the special training that leads to positions as nuclear reactor operators. After a rigorous period of instruction to gain appreciation of how a reactor works, they spend several weeks at a small reactor such as at our university, gaining first-hand experience. Their next assignment is to a reactor simulator, which has all the meters and controls of a real reactor. Finally they get to operate a power reactor under guidance and, after taking the very difficult tests administered by the U.S. Atomic Energy Commission, receive the highly prized operators' license, which certifies as to their qualifications.

Environmental Scientist

I am quite familiar with the career of a young man who is working in the environmental area. He received his bachelor's and master's degrees in biology, doing a research thesis on chemical effects in animals. He worked for a couple of years on the staff of a local governmental council that did planning for a group of counties. One of his assignments was to bring together interested citizens in the community and technical people to decide what should be done to preserve the quality of the environment -- water, air, disposal of wastes, power, etc. More recently he has moved to an organization that provides studies and advice on environmental effects, e.g., the impact of new industry on the ecology of North Carolina's coasts. He had a good basic technical background, but on the job was required to learn quickly about the very complicated interaction of our society, resources, and technology.

He has kindly identified several of the categories of environmental workers, as follows:

(a) field biologist, who collects data on the types and numbers of plants and animals that exist in an area that may be affected by a project, e.g., a water resource development. With a college degree in biology, this technician is able not only to identify species but to interpret probable trends in the ecology.

(b) environmental planner, who takes an overview of the interaction of the topography and ecology with the social advantage to be gained from the proposed urbanization of a region. A desirable education for such a person combines biology, sociology, political science, and urban planning.

(c) resource planner, who investigates the detailed physical and biological aspects of the project, seeking to resolve conflicts, find alternatives that minimize impact, and to develop reports to governmental agencies. The education required includes that listed in (b), with some experience in engineering desirable, and especially an appreciation of the relation of cost and benefit.

Nuclear Engineer

I'd like to describe the work of one of our former students in a power company based in North Carolina. He had received a degree in engineering and later took a year of post-graduate study in nuclear engineering. The utility has been engaged for the last several years in the design, construction, testing, and operation of a series of nuclear power plants. This young man served as nuclear engineer and technical assistant to the plant superintendent. His responsibilities included in the preparation of the test and operation procedures, in close cooperation with the reactor manufacturers design group, following the installation of the equipment, carrying out the measurements on nuclear, mechanical, and electrical equipment, and helping analyze the results to see how well the performance agrees with predictions. I'm sure he would tell us that getting a large and complex reactor "on line" was a demanding job, but an exciting, challenging, and rewarding experience. As time goes on, he will undoubtedly move up into management since he has a fine personality, works well with people, and is able to make good decisions.

The Research Scientist

A week or so ago, one of the former graduates of our university came back to give a seminar on his work at Los Alamos Scientific Laboratory, one of the AEC's national research facilities. He was doing the basic and applied studies required in the development of the controlled fusion reactor. As many of you know, fusion is a nuclear process for which two hydrogen isotopes are combined in an electromagnetic machine at temperatures in the millions of degrees to yield tremendous energy. In his investigation he had to use and extend knowledge from almost every branch of science and technology physics (including mechanics, heat, electricity, magnetism, atomic, and nuclear), chemistry (including reactions, bonds, and kinetics), mathematics, and engineering (chemical, electrical, mechanical, materials, and nuclear). For success in such work, the ideal preparation would be a bachelor's degree in

a science such as physics, or the reverse arrangement. As we move into the last quarter of this century, the demand for energy is almost certain to result in increased employment of highly qualified people in fusion research and development.

The principal sources of career opportunities for technicians and engineers are the electric utilities and nuclear reactors manufacturers, while those for scientists are in the federal laboratories and in a few industrial organizations. At this time, the demand for engineers is rising significantly. In a study reported by the magazine NEW ENGINEER, Feb. 1973, the demand for BS graduates in 1973 was predicted to be up 42% over that for 1972. Conversations with recruiters who have come to our campus so far bears out this estimate, with the demand for nuclear engineers well exceeding the supply, especially at the B.S. and M.S. levels. Typical starting salaries are $12,000 per year and $15,000 per year respectively.

The U. S. Atomic Energy Commission has developed some estimates of future needs for manpower by the U. S. utilities for the period 1972-1982.* The total need for additional plant operations, headquarters, and plant technical personnel is about 9,000 for this period. The total additional for maintenance, technicians, and security personnel is another 6,500. These numbers do not include the need by state and federal government, reactor manufacturers, or universities.

Employers of Nuclear Scientists and Engineers

The organizations that are hiring more people at the present are electrical utilities that have nuclear power programs in beginning stages or under way. Examples in the Southeast are:

Carolina Power and Light Company, Raleigh, N.C.
Duke Power Company, Charlotte, N.C.
Potomac Electric Power Company, Washington, D.C
Virginia Electric Power Company, Richmond, Va.
Tennessee Valley Authority, Knoxville, Tenn.
Georgia Power Company, Atlanta, Ga.
Florida Power Corp., St. Petersburg, Fla.

The companies that design and market nuclear reactor systems hire nuclear engineers, especially bachelor's graduates with excellent academic records, and those with advanced degrees. Examples are:

Babcock and Wilcox Co., Lynchburg, Va.
Westinghouse Electric Corp., Pittsburgh, Pa.
Combustion Engineering, Windsor, Conn.
General Electric Company, San Jose, Calif.
Gulf General Atomic, San Diego, Calif.
Atomics International, Canoga Park, Calif.

Other employers are: Newport News Shipbuilding and Drydock Company, Newport News, Va.; the United States Atomic Energy Commission, Washington, D.C., and its National Laboratories: Oak Ridge; Argonne, near Chicago; Los Alamos, New Mexico; Brookhaven, near New York City; Savannah River, Aiken, S.C.; and others.

Several years ago, there was a great deal of publicity about under-employment among engineers. The cutbacks in the space program did indeed release many aerospace engineers. In the same magazine cited before, engineering unemployment rate in 1972 was only 1.8%, well below the national total. My guess that 1.5% is a more realistic picture at present. If young people are to take advantage of the opportunities in science and engineering that

* "Utility Staffing and Training for Nuclear Power" U. S. Atomic Energy Commission, June, 1973.

exist now and will be available in the future, it is important that they realize that the situation has changed greatly in recent years. As we look toward solutions of the short-term energy crisis and the long-term energy problem, it is certain that technology will play an increasingly important role and that increasing numbers of well-trained and well-educated people will be required.

EDUCATIONAL OPPORTUNITIES AT INSTITUTIONS OF HIGHER LEARNING

D. Duffy
(University of Maryland, College Park, Md.)

The nuclear offerings for training and for research at colleges have increased greatly and a wide variety of courses and equipment are now available. The following comments will summarize the extent of these offerings; the nuclear fields covered; the equipment at colleges; and finally present a few figures relating to production of graduates. Nuclear graduates are needed to help staff the widening nuclear program of the country concerning the life and physical sciences and engineering.

Nearly every school of size has a nuclear course. These are more in the basic courses, as nuclear physics, with fewer in the specialized fields, such as nuclear medicine or reactors.

U.S. COLLEGES WITH NUCLEAR COURSE

Atomic & Nuclear Physics	257	Nuclear Reactor Matls.	57
Radio & Nuclear Chemistry	152	Nuclear Reactor Fuel Processing	38
Health Physics & Radiobiology	136	Fusion Reactors	60
Nuclear Technology	148	Radioisotope Uses	105
Radiation Safety	74		

The physical basis for nuclear work is the effect of ionizing radiations on materials. The radiations include, generally; photons, electrons, nuclei, and neutrons. The effect may be the reactor of a gamma ray with the gas or scintillator of a detector, e.g., in medical work or around an industrial plant. However, the effect of most interest industrially is a neutron on uranium, or fission, which is the fission reactor. The related educational disciplines are physics, chemistry, the life sciences, and engineering.

NUCLEAR EDUCATION

Scientific Basis	Discipline Concerned
Radiations through Materials	Physics
Photons	Engineering
Electrons	Chemistry
Neutrons (U & Th)	Biology
Nuclei	Agriculture
	Medicine

To support this nuclear education a variety of equipment is available; a tabulation of major equipment at colleges and some comments on their design and use follow:

U.S. COLLEGES WITH NUCLEAR EQUIPMENT

Research Reactors	34	Accelerators	
Low Power Reactors	19	Hi-Voltage	101
Subcritical Reactors	114	Linear	24
Reactor Simulators	30	Circular	46
Neutron Isotopic Sources	182	Neutron Generators	96
Gamma Ray Sources	62		

Radiation Detection

As in all fields, measurements are necessary. The geiger counter, and related gas detectors, and scintillators are in all nuclear laboratories. With these, scalers and analyzers, which are computing devices, tabulate and record the events from the detectors. Scintillators are much used in the life sciences, e.g., where a tracer isotope in a living system is measured.

Recently more sensitive solid state devices, such as Si detectors, whose crystals must be kept at liquid nitrogen temperatures, have appeared. These and the related Ge(Li) detectors have been used for only the last ten years. The signal from these detectors is processed in a computer arrangement and a plot obtained. With the scintillator or Ge(Li) detectors a spectrum of the different energies which identifies the components, versus the relative signal of each, which gives the amounts or the elements, is obtained. The gamma rays might be from a neutron irradiated paper. Recently the Ge(Li) detectors provide superior resolution of the energies, and hence the elements, and allow identification of many more elements, e.g., in rocks and ores.

Radiation Sources

Isotopic. A variety of sources of the several radiations are available. Radioactive decay sources are the simplest. An encapsulated source in a shield, often lead, is used. Gamma rays from Co 60 (perhaps as much as 2000 curies) is much used in biological studies and in chemical processes. Neutrons from the reaction of the alpha particles of a decay source, such as Pu, on Be are much used in laboratories. Most schools have at least one source with 15 gms of Pu yielding 10^6 n./sec. For more neutrons a small amount of Cf 252 is attractive. Five milligrams emits about 10^{10} neutrons/sec. Shielding of concrete, paraffin, or glass is needed. Water may be used with the source in a small tank. A Ge(Li) detector often serves to sense the gamma rays.

Accelerators. Electrical devices have been sources of radiation since the 1930's. The Van de Graaff has a moving belt to create a charge (much like one's hair does on a dry day). Potentials to 5 x 10^6 volts are achieved, and electrons, x-rays, and other radiations can be produced. Most are for physics research. A related machine is a Cockroft Walton, which uses condenser-transformer arrangements. Linear accelerators, which can be considered as using a smaller potential many times, are in many laboratories.

Neutrons can be made with these machines, and a generator with the equivalent of 150,000 volts can give 10^{11} n./sec for research. There a variety of circular accelerators with the cyclotron being probably the best known. These expensive and large machines can give energies to an equivalent of 500 x 10^6 volts. Although most have served physics research, many are contributing to the life sciences, e.g., manufacture of radioactive tracers and for tumor treatment.

Reactors. The most efficient producer of neutrons is a reactor. A 10 kw reactor yields 10^{15} n./sec. These are sizeable machines with heavy shields for personnel protection. With some reactors, water, 15 to 20 ft., is the top shield, and experiments are easily done around the reacting core. The energy goes to heat. About 3 kgm of U 235 is used. When such a facility is at power, a blue Cerenkov glow is visible. A related model is an enclosed design. The operator at the console must be licensed by the AEC. Another enclosed model is the Arganaut, such as at the Univ. of Washington. For these, the samples must be placed near the core through beam holes.

Sub-criticals. As a training device for reactors, sub-critical system of about 2500 kgms of natural uranium ($40/kgm) and a neutron source are popular. The radiation level is low and little shielding is needed. All reactors need much radiation detection equipment for measurements. Most sub-criticals have been cylindrical with water. Some have been with concrete tanks. Graphite is also used.

Equipment Layouts. The equipment arrangement to support some of these irradiation devices is extensive. A beam experiment for a reactor may have a variety of shielding and detector designs. The target area for an accelerator is sizeable. X-ray spectrometers analyze x-rays in an analogous way to the effect of a prism on light. A pneumatic system can transfer a capsule containing a sample, e.g., hair, to a neutron field around a source. After irradiation, the sample is counted. Not all the equipment in a nuclear laboratory involves radiations, e.g., a heat transfer loop may train nuclear engineers and provide data for designing power reactors.

Life Sciences

The life sciences receive much attention, e.g., agriculture and medicine. The use of x-rays is common in diagnosis. Most hospitals have a Co 60 source, e.g., 2,000 curies may be used to irradiate a tumor for a few minutes, perhaps 10 or 20 times. Linear accelerators have been applied to medicine, as has betatrons, which are circular accelerators.

Animals provide much basic data and pilot human procedures. Radioactive Fe, Cr, or Tc may be injected into a rat's heart. Blood cell life, blood volume, and organ scanning, such as a liver, may be the aim. The radioactive material for injection may come from an isotope generator with Mo^{99}, made in a reactor, which gives To^{99} for use in the animal. The animal's blood may be sampled daily after injection for weeks to get red cell life. Also a scan with a scintillator to outline the localized radioactive isotope may be made. A plot of intensity versus positions is made of an animal or a person. Thousands of such scans are made in the U.S. annually for thyroid, brain, liver and bone disorders.

Training

Many students are trained with this nuclear equipment. The levels range from technicians to operate equipment, e.g., x-ray machines and reactors, to Ph.D. graduates for teaching and research. As an illustration, the number of nuclear engineering graduates, which means primarily those who will work with nuclear reactors is sizeable: namely, 125 Ph.D., 350 M.S. and 300 B.S. annually. The Bachelor level is increasing, which reflects the demand of the nuclear power field. The graduates of the many other fields where some nuclear knowledge is required is high but less well identified nuclearly.

U.S. NUCLEAR ENGINEERING DEGREES & ENROLLMENT

Degrees	1965-1966	1966-1967	1967-1968	1968-1969	1970-1971	1971-1972
Ph.D.	118	136	116	152	140	124
M.S.	280	303	306	333	375	381
B.S.			138	181	256	291

Enrollment	1966	1967	1968	1969	1971	1972 (Fall)
Ph.D.	519	619	809	663	630	577
M.S.	627	739	749	671	810	857
B.S.		863	1011	1207	1434	1360

Summary

Much support for the equipment and students has come from the AEC, N.S.F., N.I.H., and industry. A variety of equipment and courses is available in colleges and related laboratories to assist in training in the nuclear field. My impression is that the U.S. has more such training opportunities than foreign countries. Nuclear training is at all levels, and the emphasis is on quality. To prepare oneself for such training, the high school student should study mathematics and science, e.g., physics and chemistry. English should not be neglected because ideas are of little use if not transmitted. In conclusion, the employment opportunities of the nuclear field are good, and educational programs with nuclear equipment are available.

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